Negotiating Material Description Through Technology

Anamary Leal

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Computer Science and Applications

Steven R. Harrison, Chair
Kurt Luther
Richard B. Knapp
Jane A. Stein
Joshua G. Tanenbaum

August 1, 2017
Blacksburg, Virginia

Keywords: human-computer interaction, design, materiality, ambiguity, negotiation, user interfaces, fabric

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(ABSTRACT)

Designers and non-designers alike often describe fabric in ways that are markedly different or unclear. For example, two designers might attribute qualities such as “heavy” to a material, but actually mean completely different things, despite using the same words. This ambiguity in description becomes more prominent when the designer has to make sense of the fabric remotely, such as shopping online.

This ambiguity in description presets an opportunity to study user interface design that supports, rather than diminishes, the role of ambiguity, which is often a resource in design domains. Our most important research question was: How can we design interfaces with standard interface toolkits to help designers explore and understand material remotely?

For our approach, we studied how people described distinct fabrics, from experts, novices, to everyday people and the crowdsourcing community on how they interpret fabrics. We applied that information to designs that communicated materiality and ambiguity in various ways, and studied how interfaces affected a user’s process of exploring materials and negotiating the meaning of materiality.

The most important findings are user interface guidelines that apply to designing technology any domain focused on description and ambiguity, such as design domains. Such design guidelines include: (1) the importance to communicate distinctions between description and category, (2) The role of ambiguity in design, while well-supported in the literature, is a value not shared among all practitioners, and (3) a better understanding of the different ways users negotiate with description and make sense of material remotely.

Negotiating Material Description Through Technology

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(GENERAL AUDIENCE ABSTRACT)

When presented with a fabric, even experienced designers tend to describe it in very different, often unclear, ways. For example, two designers describing the denim in a pair of jeans might refer to it as “thick”. However, they could be talking about completely different properties– one might be referring to the thread count of the fabric while another could be referring to the general feel. This ambiguity in description becomes more prominent when the designer cannot touch a fabric directly, such as when shopping online.

This problem inspired us to better understand how people describe fabric, so that we could design user interfaces that focus on these kinds of ambiguous situations. We began by studying how people interpreted distinct fabrics. These people included experts, novices, and even crowdsourced people from around the world. We applied that information to designs that helped users get a sense of the fabric in various ways, such as showing videos of the fabric, and seeing a cluster of descriptions used to describe a fabric. Using this information, we designed several interfaces, for exploring fabrics remotely. We then studied how users explored and understood fabrics remotely through these interfaces.

Among the most important findings was a set of user interface guidelines for domains that focus on ambiguity and description, such as design.

Our first guideline is that designs must communicate the difference between qualities and categories. For example, one could label all cotton fabrics categorically as “cotton”. However, user confusion might arise when presenting a fabric that is a cotton/silk blend, or one that has silky qualities but is nonetheless made of cotton.

Next, while much research shows that supports ambiguity can be a valuable resource, many practitioners instead see ambiguity as an obstacle. As such, it is important to take this into account when including ambiguous elements into user interfaces. For example, some users may just want to see “thick” descriptor, while others would prefer a series of precise measurements.

This work is interdisciplinary, spanning fields and disciplines like computer science, costume design, and Human-Computer Interaction. This work’s impact focuses on designing interfaces that support exploration of materials and description already used in the field.

Acknowledgments

This thesis and research simply could not have happened without the guidance, wisdom and encouragement of my advisor, Steve Harrison. He helped me see the forest instead of the tree that I saw, seeing lots of great possibilities in this new domain I carved out, and if I were even half as wise about HCI as him, I would be just fine.

I am so fortunate to have such a great thesis committee to guide me into the research. Jane Stein's insight into this domain was invaluable, and without her, Beth Christensen, the costume shop manager, and all the students, crafters and cosplayers I asked, this research could not have happened. Thanks to you all for the opportunity to investigate your domain.

Because of Kurt Luther, he gave me the initial inspiration me to think about crowdsourcing, and because of him, I'm a true-blue crowdsourcing researcher too. His advice was always helped push the research forward in leaps and bounds. Ben Knapp has been a supporting role as I carved different research topics, and his wisdom and experience in doing interdisciplinary research helped shape this work.

If I had to pick a post-doc with anyone in the world, Josh Tanenbaum would be an easy pick. His research helped bring the domain of costuming and craftwork as a line of inquiry to the HCI community, and that path is where my research started and will continue.

While not a committee member, Manuel Perez-Quiniones's wisdom and advice was essential was invaluable to my development as a researcher throughout my graduate career. I know would not even be here without his advice at so many points in my career.

Great things cannot be done without a community supporting that endeavor. Thanks to the Deborah Tatar and the Third Lab group for helping form such a great research environment. I'll definitely miss our discussions, group lunches and getting to know each one of you. I also couldn't have thought of doing something no one in my family has done before without the support of my family. My friends were among my pilot testers, proofreaders, encouragers, and supporters of this work.

I must also acknowledge my two cats that have been happily sitting on my lap as I have been working on my research. Also, finally, thanks to Dan for his encouragement, feedback, help in development and media, and his boundless support.

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Chapter 1

Introduction

1.1 Motivation

University costume shops are where costumes are designed, built, and maintained, where costume designers, builders, and students collaborate on theater productions. Costume designers brainstorm using a number of different tools and artifacts to communicate their visions for characters. Artifacts may come in the form of sketches, multiple illustrations, black and white, or even include swatches, among others. These artifacts enable discussion and negotiation of what the design is, is not, and could be. This discussion takes place with a number of other designers, builders, directors and other stakeholders in the production [51].

Part of this discussion focuses on the materials, and we found that designers use different, ambiguous and sometimes contradictory descriptors to describe the same fabric. For example, the word “soft” can describe different properties such as color, texture, or drape. A fabric swatch that came from an expensive Chanel suit may be to some "rich", and to others akin to a "christmas sweater". Similarly, one fabric may be "heavy” to some, but may be better described as "sturdy” or "thick” to others. For more examples, please see Section 3.1 when we investigated how costume designers described fabrics and found many ambiguities in description.

While normally the discussion in ambiguous description is a resource in the design process [22], the ambiguity-inherent descriptors become a challenge for costume designers exploring for materials remotely. If they are not near a wide variety of fabric stores and are unable to find what they are looking for locally, a designer’s options may be to travel further away to a metropolitan area with a fashion district, sometimes including air travel. Other options include enlist the help of a colleague near such a fashion district, or resort to trying to get a sense of fabrics remotely, such as shopping online.

Shopping online for materials is becoming increasingly common, as brick-and-mortar fabric stores are closing every year. Winmil Fabrics, the last full-service fabric store in Boston's garment district, closed last year[45]. Even large chains are not immune to closures; Hancock Fabrics, one of the biggest fabric stores in the country, closed all 255 of its stores last year[20].

How can technology be designed to handle such descriptions and variation in language and help designers find the appropriate fabric? Technology presents both the opportunity and the challenge, since it enables a huge amount of information on fabrics, but does not communicate how the fabric looks, feels, and drapes.

Our overall goal is to design computer-mediated interactions to help garment designers, independent of background, to have a free form, open-ended conversation on fabric and help each other find a desired fabric.

We discovered two main challenges: (1) what kinds of properties and ambiguities lie in describing materials? (2) how can we design on existing interface technologies that use these descriptors to aid garment designers to identify their desired fabric?

1.2 Research Goals

As we have discussed previously, there exists a great amount of ambiguity in how people describe fabrics. These ambiguities may seem to be an obstacle, but these kinds of descriptors in fact present an opportunity: to leverage this ambiguity as a basis for user interface design. Since this ambiguity in description is valued, our goal is not to reduce or diminish it. Rather, we want to study how to design technology to help designers make sense of a material, taking into account any ambiguities in description.

We suspect that an interface would benefit from the presentation of many ideas about a fabric, even if these are unclear, contradictory or ambiguous. Any of these descriptions could spark a better understanding of the material, along with giving the designer ideas for what they are or are not looking for.

By designing such technologies and interactions, we may also help users browse through fabrics remotely. In this case, users exploring fabrics remotely may encounter a wider variety of fabrics than they would otherwise. Ideally, this could lead a user to a better fabric than what that user originally had in mind. Using our technology, descriptions, and representations as a medium, users could also potentially better collaborate with other practitioners; it is possible that a user may understand better that a fabric swatch was similar to both an expensive Chanel fabric and a Christmas sweater.

This research is part of a longer-term research goal: the design of technology to facilitate building. By studying interfaces that help users better understand materials remotely, this empowers practitioners of all levels to more confidently explore materials, presenting more and better options for their projects. Additionally, this work lowers the barrier of entry for newcomers to build their own custom clothing, a value found in many Do-It-Yourself (DIY), maker and steampunk cultures [57].

In the farther future, our representations and ambiguous descriptors will help designers to describe and create previously unheard of next generation fabrics on a future 3D printer. However, the immediate and direct goal of this thesis is to help garment designers to communicate and describe fabrics to each other, with the ambiguities and limitations in language used to describe fabric.

1.3 Statement of Research Questions

Below are the main research questions (RQ), with main keywords per question in italics. These keywords refer to the research questions and will be used throughout the document.

1. **RQ1: what kinds of adjectives and *properties* lie in these fabric descriptors by designers?**

   We specifically seek properties that they search for and the kinds of descriptors that describe such a property.

2. **RQ2: What kinds of *ambiguities* lie in these fabric descriptors by designers?**

   This question identifies where one word may have multiple meanings and connotations in different contexts.

3. **RQ3: How can we *design* interfaces with standard interface toolkits to help designers explore and understand material remotely?**

   Touch is an important part of understanding fabric. This question focuses on how to understand fabric by using existing technologies with standard interface toolkits, and how designers generate meaning from a non-tactile technology such as that of a monitor, keyboard and mouse.

   Part of the challlenge with understanding materiality remotely is that the design domains that we studied are rich with ambiguity. Describing a material and feeling the material directly are two different experiences.

   Ambiguity helps designers come up with more, and better designs [22]. Thus, it's important that the interfaces we design preserve and champion ambiguity, an important resource in design.

   This question is the key question to the thesis. Answering RQ1 and RQ2 are essential components to answer RQ3, but the most important contributions in designing with ambiguity and fabric all come from this question.

Specifically for this thesis, this work focuses on the following design aspects:

(a) **Representation of the fabric**

Due to prior work in virtual fabric simulations[26, 63], virtual fabric representing real fabric is an option. However, since there are ambiguities in describing real-world fabric, more ambiguities may arise when seeing a virtual fabric on the screen. The virtual fabric alone may not be enough of a representation to help the designer understand the fabric.

Along with virtual fabric, we have various ways to represent the fabric visually and textually, using fabric descriptors.

We seek to learn how these different representations affect the designer's understanding of fabric.

(b) **Designing with descriptors**

From our initial studies, since ambiguity and contradictory descriptors were so prevalent in describing real fabric, we believe that designing with such unstable descriptors as a strength will help designers more than setting a taxonomy of descriptors. There exist such taxonomies [30], but from our initial studies, designers did not use them. So, our designs take into account unstable descriptors that have both ambiguous, unclear or sometimes contradictory descriptors, as a key feature.

1.4 Research Approach

To best answer the research questions above, we broke down our approaches based on four general strategies. Table 1.1 is an overview of each of these approaches and how they answer the research questions, and for each approach we describe in more detail below.

1.4.1 Exploration of Terminology in Describing Fabric

My advisor and I initiated our investigation on how costume designers describe fabric. We randomly selected fabrics and asked designers to pick fabric for a task. We collected their responses in the form of video, and recorded the descriptors used.

Then, we conducted a series of data analyses on the qualitative data. Our focus was on properties, word associations, and terms associated with particular fabrics. One example of our analysis, in figure 3.11, is one result of using co-occurring word associations and topic modeling to generate overall topics around the words descriptors used. We found a complex

Research Questions	Plan
RQ1: Properties and RQ2: Ambiguities	1. Exploration of terminology in describing fabric, focusing on properties, word associations, and fabric-specific trends
RQ3: Design	2. Design of system that uses the descriptors and properties to help find fabrics 3. Evaluations on both the different designs and representations, and the match up between virtual-real fabric 4. Iteration on designs after evaluation

Table 1.1: Table showing how the approaches answer the research questions.

network of descriptors and properties that designers used to describe fabric. These methods, among other tools, helped us find evidence for the ambiguities in describing properties of fabric.

Through these methods, we studied ambiguity at the word-level, and found the followings kinds of ambiguities:

1. Descriptors that could be applied to multiple different properties,
2. Descriptors that may describe the same property, and
3. Contextually-driven descriptors, where the describer applied a specific context to the fabric.

We also studied how expertise affected participants' understanding of materials, and found much overlap in the kinds of descriptions between experienced and non-experienced participants, validating the descriptions for system designs.

1.4.2 Design of system with unstable descriptors and properties

We designed software that facilitates describing fabrics so that the designer will get the best understanding of the fabric, inspired by prior studies, practices in the field and data.

The software used representations and interface methods to organize and present the fabric descriptions and properties found in the prior studies.

Different representations of fabric that we were interested in using included: (1) graphing methods (2) images of real fabrics, and (3) video of real fabric being manipulated.

Ultimately, we focused on images, video, and graphs of description to show information on the fabric, and we conducted empirical studies on how the different digital representations (image, multiple images, video) affected a user's understanding of the material. With video being the most useful, our designs show video as the primary visual representation, alongside descriptions.

Designing with Ambiguous Description

In addition to these representations, we also designed to show the richness of description and its ambiguities. We showed all the descriptions associated with a material. We also used those descriptions as data throughout the system.

The data itself was kept as a network of associated words to preserve the different ways a word could be used. Our systems did not use any categories, diametric qualities, or dictate a specific way to interpret the descriptors. For example, if "soft" was explored, fabrics that were described as soft in color and soft in drape would both be shown prominently. Then the user could decide what kind of soft they sought for and what kinds of fabrics worked for them.

Additionally, we showed word-level description as a handle to show phrase-level description. This meant that if users saw the word "soft", phrases like "soft color" and "soft drape", among other uses of the word, would be shown to the user.

The primary kind of ambiguity that could not be preserved was through any agreement in terms in describing the fabrics, along with any unambiguous understandings of the material through the visual representations. For example, if the fabric in video appeared to have a specific color to the user, the user would interpret the fabric of that color at first glance. We tried to mitigate this quick resolution by showing the visuals and description side by side, allowing the user to potentially see different color descriptions, for example.

1.4.3 Study

Since our system helped evaluate how designers make sense of and navigate through fabric remotely, it directly evaluated RQ3 of how do fabric representations and designs for ambiguity affect designers' understanding of fabric. Our user study asked designers to explore the fabrics, and along the way use the various features of the details to help them make sense of the fabric remotely.

1.5 Scope

This work focuses on designers who work with fabric, not necessarily those who make fabric. Those who make fabric may be more familiar with the physical properties of fabric, and thus, would use different terms than those who design with fabric. Fabric construction may encompass arts like felting, knitting, crochetting, and other ways where threads are combined to make fabric.

Similarly, we also draw the distinction of fabric consumers, compared to fabric producers, and choose to focus on consumers. Fabric producers are those who design and manufacture fabric itself. The majority of designers who design with fabric, such as fashion and costume designers, consume and purchase fabric at fabric warehouses and stores.

This distinction is important because our work serves overwhelmingly more on consumers, than producers. We feel that fabric manufacturers may have specific physical, quantitative and concrete descriptors already in place, compared to the greater ambiguity of serving the much larger fabric consumer designers.

In our studies, we focus on the United States as a specific geographic location of study, for English-speaking audiences. Our studies, especially the crowdsourcing portions, span all over the United States, with a focus on proficient English-speakers. This focus was done to better control for the kinds of descriptions we may get. We understand that descriptions and interpretations learned here may not entirely generalize to other regions and languages. The descriptors are bound to a socio-cultural context.

But, this is an investigation on how technology can use such descriptors despite the ambiguity. Again, the design and evaluation of representations are core to the analysis, since our representations can be applied to other descriptor data sets.

1.6 Assumptions

Our first assumption is that our interaction designs will generalize to other ambiguous senses like taste and smell. For the focus of this dissertation, we focus on materials like fabrics, which rely on touch. While such systems can work to other senses that generate ambiguous descriptors, such as “spicy” food or a “sweet” smell, we save such investigations in other senses for future work.

The descriptors are regionally centered, so descriptors may not be generalizable to other areas, states, or countries. Again, our major contribution is designing technology with such ambiguities. While the specific descriptors may not generalize, our designs generalize for other tasks with ambiguity.

The fabrics we chose throughout our work are a representative sample on the diversity of fabrics, but our collection may not be a fully comprehensive representative sample. We have no solid way to test this claim beyond relying on expert opinion.

Our interaction designs are not the only ways to think about fabric or about ambiguity, but we are doing beginning investigations in this domain.

1.7 Expected impact and contributions

The contributions of this work are:

- A greater understanding of the properties of fabrics, and ambiguities inherent to the way people describe them. Specifically, we deliver a network of associated words, adjectives, and properties in relation to fabric.
- An improved understanding of how to design technologies that take advantage of description and ambiguity with respect to the following aspects:
    1. Insights into the role of both different digital representations of materials and expertise in material descriptions
    2. Design guidelines for user interfaces representing materials and description

The first contribution, directly from RQ1 & 2, gives a better understanding of the ambiguities found in fabric description, which can directly serve any contexts where people need to make sense of materials remotely. Since we studied description and ambiguity across designers, builders, hobbyists, everyday people and crowdsourced audiences, this contribution is about how people describe materials, and the variations between audiences.

The information gathered as part of this contribution grants us important insights into the language people with varying experiences describe fabrics. Alone, this can guide many types of designers to better understand how people make sense of materials and the ambiguities inherent to description. In addition, this data provides a foundation for our second key contribution.

The second contribution has two parts; the first relates to our empirical studies in description. In particular, we examined the effects that different digital representations of materials and participant expertise have on fabric description. We found a large overlap in vocabulary between experienced and non-experienced participants in description; this finding shows that there is no need to provide domain-specific interfaces for description alone.

The results from this help to inform the second major contribution: design guidelines for user interface designers about how users understand materials remotely. Using our understanding of descriptors used, designers can benefit from our insights into the benefits and potential pitfalls of using descriptors as a way for users to understand materials remotely. In addition, we also discussion the impacts of different digital representations such as video versus an image sequence.

Our second contribution collectively provides improved ways to understand materials remotely. Our insights into description, ambiguities, and design guidelines, can apply to online shopping, such as online fabric stores or Etsy, to sharing-oriented contexts such as Pinterest, or even to any general situation regarding communication of materials.

Our empirical studies focused on description, representation, and expertise. The resulting insight impacts a wide variety of audiences, and how to design technology to help represent materials remotely, per individual material.

The user interface guidelines cover the process of material exploration and how users make sense of materials remotely, holistically, with multiple materials, representations and interface interactions, all together. The exploration process happens with anyone trying to find the right materials for a project.

Our design guidelines come from all of our studies collectively, with a significant portion of it from our experienced participants in our final study. Even though we studied experienced practitioners, there's potential that our design guidelines also can apply to non-experienced users exploring fabrics as well. After all, we saw similar kinds of descriptions and ambiguities between experienced and non-experienced participants.

Our guidelines in designing for description and ambiguities apply in other non-tactile sensory input as well, such as that of smell and taste. These senses, along with touch, are ones where descriptors are made early in our lives within a socio-cultural context. Our designs for ambiguity may also apply to describing scents and foods as well.

Impact on Fabric, Costume, and Material Design

With more material and fabric stores closing, our results guide UI designers how to represent materiality remotely, and improve a designer's experience of understanding fabric remotely, and be more confident in their ordering choices. While the focus of this work is not search or browsing user interfaces, the results of our work affect how to represent materiality, like fabrics, remotely.

Overall, our research helps designers identify and ultimately find a desired fabric without feeling it directly, but our representations and descriptors also help in generating next generation fabrics with technologies including additive manufacturing (3D printing). Imagine the 3D printing of fabrics, now with the opportunity to more precisely control the location and architecture of multicomponent fabric.

Presently, a strategy to design and manufacture a desired fabric is start out with a base fabric with a particular good property, choose a non-ideal property and continuously make and evaluate different weave designs to improve that property[31].

This work does not lead to efforts to replace nor substitute the necessity for tangible understanding, since feeling these materials is paramount in these domains. This work seeks to design technology that supports and gets inspiration from existing practices in these design domains.

1.7.1 Uniqueness

From a usability perspective, designing for these descriptions and the resulting ambiguities is challenging because the technology itself is far less ambiguous in comparison. For example, computer science students may learn the descriptors of a programming language in a classroom, such as "object-oriented, multi-threaded".

In contrast, even small children start learning about fabric as soon as infant clothing is worn [47], along with learning in a socio-cultural context. With these factors, the vocabulary for material description is diverse. Given the history of fabrics, well woven in human history itself, there are many taxonomies and standards for describing fabrics alone, more detailed in the related work. Because of these ingrained words, standardizing or normalizing fabric descriptors is not the appropriate solution.

We focus instead on the descriptors, connect the potential ambiguities and properties to those descriptors, and design technologies around the ambiguities.

1.8 Overview

The document is structured in the following chapters:
Chapter 1 — Introduction
Chapter 2 — Related Work
Chapter 3 — Initial Explorations in Description
Chapter 4 — Media Crowdsourcing Studies
Chapter 5 — Exploration of Materials in the Field
Chapter 6 — Fabric Web Application
Chapter 7 — Ambiguity Interfaces Study
Chapter 8 — Implications for Design & Design Guidelines
Chapter 9 — Conclusions & Future Work

Below is a summary of the remaining chapters, and the conclusions of each:

1. Relevant prior work from the literature.

2. Exploratory studies that helped identify compelling research questions, where we asked

an expert costume designer and several novices to describe fabric. We identified a series of words, sometimes contradictory or ambiguous, that were used to describe fabric. We observed similar trends when we continued investigating with additional non-designers.

We found an oft-reused and limited set of vocabulary used among designers and non-designers alike. We also performed a word-focused text analysis on the ambiguities. The core finding of this analysis was that different words may describe the same property, while the same word may be used in different ways. These studies show promise in description-focused, user-driven interfaces to help communicate materials remotely.

3. A series of controlled studies on how levels of expertise and different types of digital representations affected participants' understanding of materials. We collected descriptors on fabric from both in-person and online crowdsourced participants, and compared the kinds of words they use to describe fabric.

   Like in the earlier description studies, we found little differences between how experienced and non-experienced people described fabric. In terms of digital representation, video was strongly preferred over images, as it closely matched what users would do with real fabric. We also saw potential for employing word and phrase-level ambiguity.

   For obtaining material description in practical applications, our studies recommend employing crowdsourcing description to get the majority of information, and supplementing with descriptors from a small number of experts.

4. An examination of shared practices in exploring materials, obtained from practitioners' anecdotal data from the prior studies.

   Among the shared practices, we found the following approaches:

   (a) Fabric-focused approach: seeing a wide assortment of fabrics.
   (b) Quality-focused approach: exploring materials by terms, qualities and ideas of what the material should be like.
   (c) Combined approach: iterating between fabric and quality approaches.

5. The design, iteration and implementation of our evaluation system with various ways of representing materials and interacting with materials, inspired by prior studies.

   We designed a system to help users explore 45 different fabrics, with descriptions, resulting ambiguities and representations from other studies. Each way of viewing fabrics within the application was directly influenced by one of the shared practiced previously identified. Several areas of the application were designed to encourage negotiation of the ambiguities inherent in description. In showing words relevant to a fabric, we showed unique phrases associated with the word, letting users negotiate meaning between the different ways to use the word.

6. An evaluation focusing on RQ3 studying our system and how its different views and representations of fabric affect designers' understandings of fabrics.

   We observed various levels of negotiation between the descriptors and the visual representations, specifically with the fabric's individual view, as people looked at both the visuals and the descriptions to make sense of the ambiguities. We found a specific kind of ambiguity where users could not fathom a fabric having two different fiber contents, thinking of them in terms of two different categories of materials, and later realizing the feasibility of this notion.

   A subset of participants did not have much regard for the descriptors, suggesting that concrete definitions and qualitative measurements of the materials would be superior. In many cases, these participants were themselves using incorrect or inaccurate interpretations of definitions themselves.

7. Overarching implications for design, and resulting design guidelines for user interface designers building in this design and descriptor-focused domain.

   We found that users employed a variety of different ways to understand the fabrics. These ranged from from relying primarily on a collective understanding of the material, to a focus purely on the aspects of a single material, to only valuing exactly what they could see for themselves.

   From these prior studies, we deliver the following design guidelines:

   (a) The importance of communicating qualities versus categories, the distinction between collective and individual information, and the role of uncertainty in general.
   (b) The impact of ambiguity in design; while ambiguity's benefits are well-supported in the literature, this sentiment may not be shared among all practitioners.
   (c) Consideration for uncertainty and its role in the user's values. Some users may try to make sense of others' interpretations, while others may value their own understanding above all.

8. Conclusions and future work discussing the next steps for this research. This includes proposals to better understand users' values in regard to uncertainty, as well as designing technology to support a collaborative discussion about particular words' meanings.

Chapter 2

Related Work

2.1 Fabric Descriptions and Representations

There are numerous standards and taxonomies present to describe fabric. Kawabata's work, a prominent work from fashion design, was one of the first to take physical, quantitative properties of fabric, ask experts to rate fabrics based on those properties, and generate a vocabulary of words to describe specific aspects about fabric, such as the stretchiness and drape[30]. Minazio evolved the work and provided a series of simple quantitative tests to evaluate thickness, bending, and stability, among others[23]. Our approach is the reverse of Kawabata's approach; we begin with the vocabulary of current designers, and then reach to the physical properties. We also use the descriptor set to design technology interactions where designers may not have access to the fabric directly.

Park et al saw the challenge of evaluating drape, or total hand, and generated a fuzzy neural network approach to evaluating total hand, by giving mechanical properties of knitted fabrics as input, and output is the total hand. The nerural network system was later compared to the Kawabata standards of evaluation as well[48]. This approach is one way to leverage algorithms to determine and understand fabric. Our algorithms and designs lerverage a designer's words, descriptors and other properties of fabric to help represent it.

Researchers have also inquired on describing fabric, and asking participants to cluster to help resolve ambiguity. Thomas et al. also explored how people described fabric with the goal of allowing consumers to make informed choices about fabric when shopping for clothing online. The researchers performed a literature survey to find 69 commonly used descriptors by fabric experts and asked naive participants whether they understood or used such words, replacing 20 expert words with 29 words from participants, and filtering emotional or hedonic words. They then conducted another study that asked participants to group descriptor words based on their familiarity and similarity.Their results group descriptors together; for example, "warm" is grouped with "cold", and "soft" with "light"[59]. Similarly, Ishikawa et al gave a similar study of having participants describe words, then asked to group and cluster, with the added analysis of grouping guided by the Kawabata Evaluation System[30], resulting in visual and tactile terms [28].

Our goals are similar, but our approaches differ because a designer describing fabric as "expensive" may be of value to another designer wanting to design high-end garments. Additionally, such a methodology only puts "soft" with "light", instead of "soft" with "warm" or "fluffy", implying a textural property. "Soft" may also be described with a different property like color, but such a grouping would not catch such an ambiguity. Furthermore, our target audience are designers themselves, not clothing shoppers. Though not our main research questions, we are curious to see whether there are differences between everyday non-designers, compared to designers.

2.2 Fabric-Relevant Systems

Prior work in the fashion and costuming domains have delved into how to evaluate, describe and represent fabric, where we got inspiration for this work. Luible et al evaluated new methods to conduct subjective fabric evaluation for virtual fabrics on haptic and tactile interfaces, particularly ones where the user interacts with two fingers. The work adapted existing AATCC procedures[3] for two-finger interactions[39]. Our work relies on existing technologies that are not considered a haptic and tactile interface, but such work gives us different ways to evaluate our virtual fabric, despite our system using no haptics.

2.2.1 Garment Design

A significant portion of fabric-relevant systems are garment design simulations. Garment design, can be accomplished by creating virtual designs using virtual fabric[26, 63], including refinements that target specific fabric properties like Herbert's work on simuulating drape [25]. Decaudin's work provides a 2D sketching system that focuses on virtual clothing for virtual 3D modeled characters [15], which applies less to our research since we manage real-world fabric, compared to simulated fabric that has to appear to be fabric.

Kim's thesis work looked at consumer perceptions of clothing, including fabric characteristics, when online shopping. The majority of their participants trusted that color seen on the screen would be what they expected. Additionally, participants perceived an online garment's comfort and drape by drawing on prior experiences with that particular kind of garment or fabric. In regard to texture, participants relied more on the garment's description and fiber content information, rather than the image [32]. Kim's work shows that even consumers rely on descriptions of the garment, prior experiences, and context to understand some characteristics when shopping for garments online. We are curious about what kinds of information designers would rely on to understand fabric.

Representing real-world fabrics using virtual fabric simulations are also not novel, and our work aligns to study descriptors as another representation. In one of the later studies into the design of virtual fabric interfaces, Atkinson et al. collected descriptors and gestures that participants used on real-world fabric, extracted key features and gestures from the set, and implemented those gestures onto virtual fabric in an interactive mobile app on an iPad. The gestures were pinching, stroking, and scrunching the fabric. The iPad displays a piece of fabric draped flat, as though the fabric were draped on the iPad itself. As the user performed gestures on the fabric, the application played, rewound and replayed videos of fabric performing the appropriate behavior. Additionally, the researchers evaluated recording the fabric in different[5]. Our work leverages on these gestures so that our representations also can have the same gestures. Additionally, to expand the gestures set, we consulted a seasoned designer expert in how designers understand fabric, including gathering, draping on one's hands, and seeing the fabric from a distance. Our work evolves such work by including drape on hands and on objects. Fabric lying on a flat surface like a floor does not reveal its drape by itself.

Fabrics are represented in various other ways beyond the context of clothing. For example, from a modeling and engineering perspective, there are several model hierarchies used to represent fabric for fabric composites to make optimal fabrics for a task[37].

There's much interest in representing fabrics for 3D modeling systems. Miguel et al at Disney Research built a device that manipulated real-world fabric, such as twisting and stretching the fabric, and collected information on fabric to bring simulate the fabric in the virtual world, with the same manipulations, automatically with an estimator algorithm [42]. Their work would be helpful in our virtual fabric simulations, but their results are limited to 3D modeling, and would only need to simulate fabric, not get specific known parameters about the fabric that designers and practitioners would be interested in.

Other work from Disney Research mapped fabric descriptors, such as softness, heaviness, and drape, among others, to parameters in virtual fabric simulations, allowing for 3D modelers to alter a virtual fabric based on common descriptors. They asked people to rate videos of virtual fabrics, and performed a regression analysis on the ratings and the virtual fabric simulation parameters [55]. While this approach would be helpful to simulate fabric, this approach would need to be heavily defined to be suited for those that work with real fabrics, with information that makes sense for them.

2.2.2 Fabric Search Systems

Torry et al's study on how people engaged with craft search for craft knowledge online was insightful for how our users also engage with materials remotely. Their work found that users iteratively refined and changed their keyword searches, with the challenge of the limited and domain-specific vocabulary in individual craft domains. To supplement that strategy, users subscribed to the forums and kept their social network informed of their latest projects.

These communities often shared techniques, specific terminologies and project ideas [60]. This work emphasized the importance of communities in finding the right knowledge that a craft person may be looking for.

Kuznetsov's & Paulo's work in DIY culture gave us design values relevant to part of the design domain that guided our thinking for the research. They studied participants in Do-it-yourself(DIY) culture, studied their practices, and delivered implication for design in the domain. One of the design domains is the value of sharing and relying on the community to support one another [36], and this research is meant to allow the community's opinions of a material to be visible to the user, regardless of how unclear or ambiguous it may be.

Systems In-Practice

In exploring materials, we came across different kinds of search interfaces. While what we have designed is not studying search user interfaces, in general, we still wanted to glimpse at how exploring materials remotely was done in practice, and the two most noteworthy ones were JoAnn Fabrics and Google Image Search & Filter interfaces.

Later sections explore more specifically how our study system compares to these interfaces in section 6.3.3, but this section highlights in general how these systems are designed, and how they take into account or do not account for ambiguity.

The first is JoAnn Fabrics search interface, which have a search text box, and allows the user to narrow down based on selecting check-boxes that match their criteria, such as the brand, color, and fiber content [2]. This interface helped motivate our work, since our work studies how categories do not serve a part of the population of those who design with fabrics. A builder may have flexible metrics in terms of the kind of fabric, allowing for multiple categories to work. But these categories have a specific meaning and interpretation according to the store, and that interpretation may not be what the builder has in mind. A designer may think of fabric for dance, but what they may be looking for can be anywhere in fashion fabrics, dancewear, cosplay fabrics, among others. The core opportunity from reflecting on fabric stores is the research opportunity to explore designing interfaces that employ the user's own language and study how the explore materials and the ambiguity inherent in describing materials.

The second noteworthy search interface is Google's Image Search. Normally, Google may be seen as an unusual choice to compare, since it's a general search engine, not specific to materials. In May 2016, Google released filters below the search terms that narrowed down the results. Each filter was a word relevant to the search query, and if selected, it would only show results that matched that query [1].

The biggest key difference between our study and a search user interfaces like Google's image search is that we want to study how users make sense of what they see; we expose and show why terms were co-occurent to one another, and why someone mentioned that term in-context. While our datasets have many fabrics, our success rate is not measured by whether someone finds a fabric. Rather, this work focuses on how users make sense of materials. Google's goal in its search interface is to help you find what you're looking for, not necessarily to understand process.

2.3 Ambiguity & Polysemy for Design

2.3.1 Ambiguity

Many field of study negotiate and apply ambiguity in different ways. Russell's paper in affective intelligence describe how participants sorted and ordered different states and emotions to result in emotions placed in a circle, on a two-dimensional circular space, called the circumplex model[53]. More recently, Christie and Friedman's study of emotions, with a focus on the autonomic nervous system, posited a multi-dimensional space of emotions, by showed participants films and recording their ECG, blood rate, and skin conductance, among others. [11]. Lovheim posits a three dimensional model for emotions based on levels of noradrenaline, domanine and serotonin[38].

We may choose to apply methodologies like earlier affective intelligence work to make a dimension of fabric. Such an application is not currently one of the main research questions, but is an interesting side research question. Our concern is not as much the words used in fabric, as much as the ambiguities in the descriptions for design, and representing tangible objects like fabric in non-tangible ways.

Verbal ambiguity from psychology is well studied field that we leveraged to help understand the ambiguities in our work. MacKay's definition of ambiguous is "any stimulus pattern which is capable of two and only two distinct interpretations"[40], who later studied relationships between perception time and and different kinds of ambiguities in sentences. Noam Chomsky's book "Aspects of Theory of Syntax" breaks down ambiguities into different levels of ambiguity, and the level most relevant to our work is a lexical ambiguity, where a word of sequence of words with the same grammar, may have multiple meanings[10].

Despite ambiguity to be an obstacle to design, many see ambiguity as a resource for design. Gaver posits that the world is ambiguous, ambiguity helps designers express their context and concepts. It also allows for many people with different contexts to express multiple interpretations on a concept[21].

He describes three kinds of ambiguity: ambiguity of information, where we see incomplete information, ambiguity of context, where there different interpretations are due to different ways of thinking, and ambiguity of relationship, where established experiences are applied onto new ones[21].

The chief ambiguity this work addresses is one of context, where there way be different interpretations on a fabric. In our first study, shown in a later section 3.1.8, one piece of a Chanel suit, rich in a societal context in the past, was seen as a Christmas sweater by one designer. Our work then, presents potentially contradictory perceptions in different ways, both visually representing the fabric and textually. Please see our final designs on 6.1.5 for more details. This work aims to conserve and present ambiguity for designers, so they can use it as a resource.

2.3.2 Ambiguous Designs

Ambiguity has been imcorproated in varous technologies and designs in the literature. Rasmussen et al's work explore how ambiguity can be designed into various actuator interfaces, such as a public shape-changing chair, or an instrument made of hovering balls where repositioning the balls changed its sound. They incorporate ambiguity in actuator interfaces by either relying on very little prior interaction modalities, trying to be as completely foreign to the user as possible, or designing radically different behavior or different materials into familiar objects [52]. This work differs from such designs since ambiguity is inherently present, and want to preserve and present it, compared to designing new ambiguity into an object.

Similar kinds of ambiguous designs include identifying different kinds of materials in objects in a photograph. Bell et al made a crowdsourced catalog of materials, and textures of objects in submitted photographs. Participants aided in the segmentation of different objects in a photograph, labeled the objects based on what they were and a estimate on the material (Fabric, fur, wood, metal, etc)[7]. Our work plans to also crowdsource descriptions as well, for similar reasons as this work. Our descriptors also encompass multiple material and texture descriptions, making the dataset bigger and more challenging.

2.3.3 Polysemy

Polysemy, or the notion one word or phrase can have many meanings, is a prevalent area of study, and one similar to ambiguity in our work. Georgiev and Taura studied polysemy in dialogue occurring in design reviews, and found a connection between higher polysemy in nouns and successful design ideas [22], relevant to better designs with fabric, the domain we focused on.

Polysemy literature also guided us on what kinds of qualities could be captured from describing fabrics. Cranny-Francis discusses semefulness, or the notion of multiple significant understandings, on touch, and discusses that because we're are embodied beings, touch itself can evoke significant subjective meanings, whether physically, intellectually, spiritually or politically [13]. Chapman posits that the meaning of artifacts comes from three qualities: polysemy associated with the artifact, contextual sensitivity and consensus for communication [9]. We chose to directly capture the polysemy of these variety of fabrics, also any context that participants share. We capture consensus on whether there were repeated mentions of the same or similar descriptor on the same fabrics.

2.3.4 Computation and ambiguity

Computation has sought resolving ambiguities. Word sense disambiguation is a problem to understand the words in context in a computational way. Such problems are considered among the most challenging problems in artificial intelligence[44]. Removing ambiguities is a part of the challenges in fields like natural language interfaces (NLI), all run by voice queries[49]. Other work focuses on query interfaces, based on one query accessing a large amount of databases online and presenting information to the user. One work aims to dynamically make labels for search query text boxes, to help users input valid and clear queries[17].

Eppler et al studied different kinds of ambiguities in information visualization, such as symbolic and iconic ambiguities that are purely visual ambiguities[18]. Our ambiguities thus far are in words themselves. In addition, there may be some confusion or ambiguities when comparing to visual components to the words themselves. That is, a fabric could look like cotton, but it may be labeled as silk.

2.4 Crowdsourcing Descriptors

In addition to prior work that crowdsourced descriptors for part of their studies[59], we also find crowdsourcing as a way to obtain many diverse descriptors. Because of this, we leverage on crowdsourcing prior work to help guide our designs.

Crowdsourcing has been a way to obtain complex, and ambiguous information, like those in describing materials. Palen et al's work explore crowdsources OpenStreetMap, an open sourced map, specifically when maps had ever changing information, like those in catastrophes [46].

Kittur et al' work analyzed how to capture and integrate schemas from the crowd in relation to information foraging, merging multiple interpretations of information related to reviews of products. Their work investigated how to design and evaluate asynchronous crowd aggregation, where many people read a review, and categorize the reviews with respect to different aspects of the product. Participants meta-reviewed other reviews. For example, participants may categorize a review about a camera's video quality as a "video quality" category, so future users could get higher-level insights on products [33].

WittleSearch is an image search reliant on user's different interpretations of images, and, using crowdsourced opinions of images relative to one another, enables for relative searches like "shoes like this, but sportier and less pointy" by Kovanshka et al. The researchers represented and organized consensus based on clusters on a graph, to represent the multiple overlapping interpretations that users may have [34].

Both works show how we could crowdsource the interpretation of potentially ambiguous information, by asking others their interpretation. But, their interpretation may not be what the writer intended, even if both use the same kinds of words.

We could also design systems that ask designers what properties do they mean, like in Kittur's work [33]. But, like in following from the baggage-of-words information model from information architecture [43], more discussed in section 2.6, their properties would also be associated with a collection of additional associated words, which would also be subject to inquiry. While this exercise is possible, the opportunity of this research is to let the users make sense of someone else's descriptors, but not necessarily definitely set how that descriptor should be interpreted.

Additionally, consensus on a descriptor does not necessarily mean that that's the correct, accurate, or only interpretation of a fabric. One descriptor that has no consensus may be the perfect descriptor for someone. For example, if a fabric was described as "for a pharaoh", describing a specific character. Eventhough that description may pop up once, this descriptor may help a designer who is designing a show in an ancient Egyptian setting, and wants a material that reads from that setting.

2.5 Representations of Similar Materials

Prior work has also tackled the challenge of ambiguity in description, but with different approaches. Feinberg et al observed the challenge of ambiguous information in the metadata of videos, and explored how to integrate such data in different interfaces. One of the systems they designed was the Scalar system, a relational network of descriptors, which supports our emphasis on networks. Their approach was to study the importance of data integration as a design process, and to study texture, specifically, the relationship between data infrastructure and data environments [19]. Our work's approach in designing interfaces was to leverage off of existing practices, while their work was more on design integration. But the challenge of descriptor remains the same.

In addition to virtual cloth simulations, other domains present alternatives to represent fabric. Industrial designers use graphs to get a sense on a variety of different materials[4], such as that in figure 2.1. We considered these fabric representations and assess its usefulness for designers.

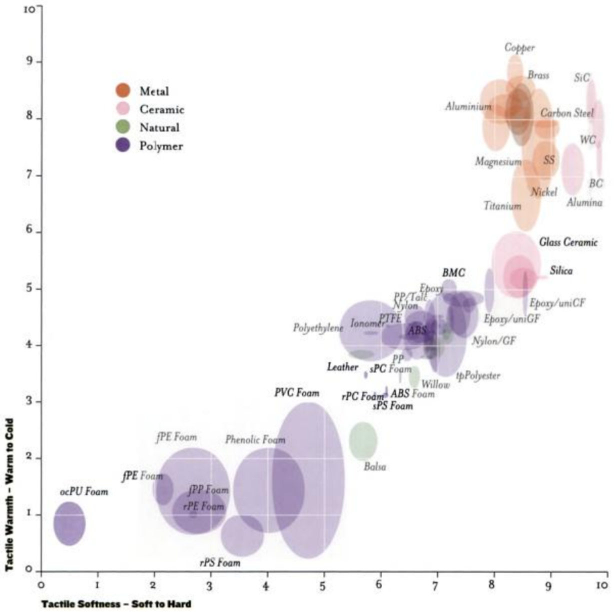


Figure 2.1: Snapshot of representing multiple materials on a graph, from an industrial design book[4], where textural softness and textural warmth are plotted.

2.6 Theory

2.6.1 Information Architecture

Many aspects of this project discuss how to organize and represent fabric to help users understand different fabric properties. The work relies in part on information architecture, where fabric has a series of properties, descriptors and behaviors. Morville's book on information architecture posits that words are a part of the interface or how users understand a system. A word like "soft" may have a large baggage of associated words, properties and fabrics associated with it, such as "fluffy", "smooth", or even "cats". A word may have a large amount of context surround it [43]. But words are not the item itself, and in our observations and in our studies, the baggage word metaphor rings true.

Morville recommends having multiple taxonomies or ways to organize or represent fabric, which is an influential guideline that stays with this project as we explore multiple representations that show multiple aspects of the fabric itself. For example, dualism is a way of understanding information by presenting metaphors, such as presenting opposites like understanding "hot" with "cold"[43]. Dualism for evaluating fabrics is a common practice, both in evaluating systems representing fabric[5]. More formally ,the American Association for Textile Colorists and Chemists has a procedure for subjectively evaluating fabric by putting a numbered 5-point scale between dualism pairs[3].

Since one descriptor could be connected to multiple other descriptors and properties, we chose to not have descriptors pitted as opposites. "Thick" and "thin" may be presented as opposites, but a designer may mean a fabric is "thin" in yarn width, but "thick" in fabric thickness. For this work, we do not impose dualisms on these definitions, and rather favor capturing as much context as we can from the descriptors themselves so that a fabric can be thick and thin. By avoiding dualisms, the data stays true to the designer's descriptions. If the data shows evidence of dualisms between terms, then, we may consider using such dualisms. But for now, we choose to not use dualisms in any of our evaluations to remove as much bias from the experimenters and bias between designers.

De Sousa explored semiotic theory in the context of HCI design and how designers communicate designs to better understand user interaction with signs and analogies [14]. Our work is related to this in observing different communication channels from different people to understand the fabric itself, and our analysis is conscious of analogies and metaphors used in this communication channel.

2.6.2 Embodied/Tangible Interactions

This work positions itself in embodied interaction, where it describes “the creation, manipulation and sharing of meaning through engaged interaction with artifacts”[16]. Specifically, garment designers learn about fabric by feeling it directly between their fingers, draping the fabric over their hands or on some other object, waving fabric, seeing how the fabric looks in different lighting conditions and distances. The task is not all a tactile nor all visual of a task. Understanding fabric is similar to generating meaning for embodiment[16]

Tangible approaches are similar to a fabric-based approach. Ishii's Tangible Bits seeks to incorporate mapping physical objects onto virtual objects, including surfaces and graspable objects to present educational spaces. They found that users understood the metaphors well, such as understanding what a flashlight is helped to communicate how lenses work [27].

Craft, a relevant subset of skills in costume design[51], has an intrcicate and strong connection to hands, and tangible interaction[41]. Due to the tangible nature of fabric, we seek to evaluate conditions where hands are involved.

Chapter 3

Initial Explorations of Description

3.1 Exploratory fabric study for designers

Our first exploratory study focused on how novice designers described fabric, and whether there were ambiguities in their descriptors. We asked designers to describe fabric as a way to get the most salient properties of that fabric, as a way to get a sense of the fabric.

We could have asked designers to describe fabrics relative to a series of properties, but the designers would describe the fabric in a structured manner, rather than what is salient from the experience of holding the fabric. Furthermore, such a structured inquiry would miss compelling contextual descriptors, ranging from ideas of what to use with it, anecdotes relevant to the fabric, and beyond. In order to keep the task open-ended, we initially asked participants to describe fabrics.

We began by obtaining a wide variety of different fabrics featuring many kinds of textures from a professor at our university with expert knowledge in costume design. Figure 3.1 shows the diversity of fabrics selected.

In our initial interviews, this expert discussed the ways people describe fabric, mentioning how one piece of fabric could have different meanings to different designers—even between designers that have worked together before. This expert also noted that understanding fabric is more challenging when the designer is unable to feel the fabric directly, such as when shopping online.

With our diverse set of fabric samples in hand, this study set out to examine these ambiguities in describing fabric.

Figure 3.1: Our wide selection of fabrics and textures recommended by our local expert. We refer to fabrics by incrementing number, in left-to-right, top-to-bottom order, such that the dark with pink spots is #1.

3.1.1 Questions

With this study, we focused on research questions RQ1 and RQ2 directly:

1. **RQ1: what kinds of adjectives and *properties* lie in these fabric descriptors by designers?**

2. **RQ2: What kinds of *ambiguities* lie in these fabric descriptors by designers?**

To better understand the ambiguities in describing fabric, we chose to give fabric samples to our participants to describe.

For this study, no technology shy of data collection tools was involved.

3.1.2 Participants

We asked an expert and seven students from her costume design class on how each describe fabric. The expert, while not a participant, nonetheless provided us with a diverse set of different fabrics including detailed descriptions.

The seven student participants were in an undergraduate costume design class, aged 21-24. All of the students were pursuing a bachelors degree in Theater Arts. One of the participants was pursuing a second bachelors degree. Two participants were double majors, while two others were pursuing an additional minor in another field.

All but one participant had experience in artisan crafts (such as ceramics, pottery, or clay) or at least one semester from a costume lab (where students learn how to hand and machine sew, hem and other tasks to help make productions). In addition, five of the six student had additional experience in other artisan crafts such as jewelry, woodwork, and set design.

All had experience in clothing, apparel, or costume design through the costume design class itself. In addition, two of the students had taken additional classes in costume design, with one having already designed costumes for two shows.

3.1.3 Tasks

For this study, we had participants perform two main tasks:

1. **Describe a character with fabric swatches.**

   This exercise came directly from a costume design class assignment, where students had to find swatches to describe a particular character provided. The assignment was to help students think about colors and textures for these characters. There were five characters provided, each with different age groups, genders, occupations, and personalities.

   (a) A 90 year old—male or female

   (b) A student age female who is unsophisticated, unknowing, and innocent of the world. Similar to the character Laura from the play *The Glass Menagerie*—a shy, sheltered, mentally fragile teenager [64]

   (c) A male or female child from 5 to 10 years old

   (d) An up-and-coming starlet who is not yet a superstar

   (e) A high-powered banker from New York City

This activity was more closely bound to theater, where clothing is made to help communicate a character, than to other fields, such as fashion design, which has different goals. While this could potentially limit the scope of our findings, our primary goal was to identify ambiguities in designers' thinking, which is not itself limited to costuming.

Being part of a costuming class, this assignment had been graded. However, we chose not to collect grading data since it was not particularly relevant to our research questions. Prior to the study, we asked participants to have their assignment on hand, but if the participant did not have the assignment, this portion of the study was skipped.

2. **Pick fabrics to make a vest for a colleague.**

   This task was similar to the first task, except that the participant would have to choose someone they were familiar with as opposed to a fictional character. This person could be a colleague, classmate, or friend approximately the participant's age and in college.

   Instead of having the participant design all the clothing for this person, we chose to focus the discussion on a specific kind of garment. Furthermore, in order to avoid having the participant simply copy what the chosen person actually wore, we chose a slightly less common garment: a vest, or a sleeveless sweater. This study was conducted in the mid-fall/early winter of the year in a temperate climate, so the kinds of vests in this context were not summer or light vests. This task helped participants explore our samples of fabrics, along with a large bin of fabrics in the room, as shown in figure 3.2 below.

   We randomly assigned two fabrics from our collection to the participant, and the moderator handed the two fabrics to the participant, asking whether they would use any of these fabrics for the vest, and why or why not. The moderator then asked the participant to identify similarities or differences between the two fabrics. Finally, the moderator asked the participant to find fabric swatches more suitable to the task, whether from our collection of fabrics or the fabric bin.

3.1.4 Study Design

While this study was meant to be an exploratory study, we constrained the vocabulary to focus on a participant's own words, and on a subset of fabrics to describe. For example, participants described fabrics from a existing group of fabrics, as opposed to having complete freedom to envision any sort of fabric.

During the interview, the moderator did not introduce any new terms in their dialogue with the participant. The moderator wrote down any descriptors or adjectives used to describe fabric, and would then ask the participant to either clarify the term or to describe other fabrics related to the term. We obtained both better understanding of such terms and what they meant relative to other fabrics.

Figure 3.2: Our wide selection of fabric used for the second task in the study. The image shows a large fabric bin, with a smaller plastic bin inside, all containing snippets of fabric.

All tasks were performed as part of a *semi-structured interview*, with a base set of questions and the allowance to ask further questions based on what the participant said. We collected the data by recording a video of the participant's hands as they interacted with and described the fabric. We also took pictures of the participants holding each piece of fabric to record how they held and felt the fabric. The moderator also took notes on each descriptor used for the fabric.

3.1.5 Analysis

Since the nature of this work is communicating descriptors of fabric and to analyze the connections between relationships, we chose to perform content analysis [35] on the individual descriptors. Specifically, we noted word associations between words, frequency counts of words, and topic modeling for clustering descriptors.

This data was then transcribed verbatim and put into a table where the columns were the individual fabric described, and the row was the participant number. The data was converted as input into the statistical software R, using the package `RTextTools, topicmodels, TM, and igraph`, all having relevant topic modeling and graphical packages needed to accomplish our analyses.

Using R, we cleaned the dataset of filler words and descriptors, including “good”, “like”, “the”, “sure”, and other similarly less insightful and unique terms. Afterwards, the words were converted to root words, so that words such as “heavier” and “heaviest” would count as the same word.

As a cursory analysis, we first briefly compared the expert’s descriptors of fabrics with the participants’ descriptors to see if there were differences. As a less cursory review, we identified the most popular words in the dataset. If there were words used often between participants, we wanted to observe whether such words were meant in the same way.

We then conducted a word association analysis, first on the most frequently used words, then on the whole dataset. In this word association, if a participant said "not soft, very rough, bulky" to describe a fabric, “soft”, “rough”, and “bulky” would be equally co-occurent and associated with each other. One interpretation could be that they describe the same property. We also randomized diversity of different fabrics to minimize coincidences, such that multiple fabrics can be neither, either or both “soft” and “rough”.

To identify overall trends in word associations, we generated a word co-occurrence graph, where words closer to each other, such as those mentioned close to each other, have a higher association that word pairs that were not mentioned together. To focus on relationships between words, graphs in this section show descriptors that have been used more than once.

To see further connections between words, we first conducted a topic modeling analysis to cluster words together based on association. We specifically used Latent-Diritchlet Allocation analysis for topic modeling, which offers the most flexibility in data [8]. We wanted to see if one word was associated with another word, possibly indicating that the words were synonyms, antonyms, or having some other relationship. Multiple words could be in different clusters to represent different meanings.

We chose to limit the groupings to four groups(k = 4). We ran the analysis more topics, but found too much overlap in the words to make a meaningful interpretation. To return the best clusters, we did 1500 repeated runs of LDA, returning the best model of those runs.

We performed all analyses on related per participant, per fabric and for the overall dataset.

3.1.6 Relevant Equipment and Software

All data was recorded using a Microsoft Surface Pro using the built-in microphone and front-facing camera. The device has a 10.6" LCD display with 1920 x 1080 pixel resolution, 4 GB of RAM, and a Intel Core i5u processor.

All data was converted to a CSV file which was used as input to the statistical software R, which had all relevant topic modeling and graphical packages needed to accomplish our analyses.

3.1.7 Procedure

A moderator provided the participant with the pre-questionnaire first. Then, the moderator asked the participant whether they had their assignment on hand. If so, the moderator asked the participant to talk about and present their fabric choices for each character.

The second task started with the participant receiving two swatches of fabric, randomized prior to the interview. The moderator asked whether the participant would use the provided two fabrics for a colleague's vest, and to describe why or why not. The moderator noted any adjectives or descriptors used, took pictures of the fabric swatches of each character and asked the participants to compare and contrast both swatches on further similarities and differences.

Then, the moderator asked the participants to explore other fabrics that may be more suitable in the pile of provided swatches or from a fabric bin. When the participant chose and picked up different fabrics, the moderator asked similar questions about suitability for a vest and about the similarities and differences between the initial two swatches and any newly introduced swatches. If the fabric chosen was new, the moderator kept a swatch of a similar fabric to keep track of it.

3.1.8 Results

We organized our results by fabric-specific trends, and overall, with all the participants' descriptors. Participants collectively said 1022 words to describe fabric, and after cleanup, there were 401 descriptors. Without repeating descriptors, there were 132 unique descriptors. Participants used on average 12.1 descriptors when describing each fabric.

Task 1: Design for Characters

Two of the seven participants described their assignments. Figure 3.3 shows one example of fabric choices for an old man. The participant based her response on the older men she saw at church.

Figure 3.4 shows the second participant's answer for the same character, who drew her experiences from her grandmother. Figure 3.5 shows the responses for all characters for this task.

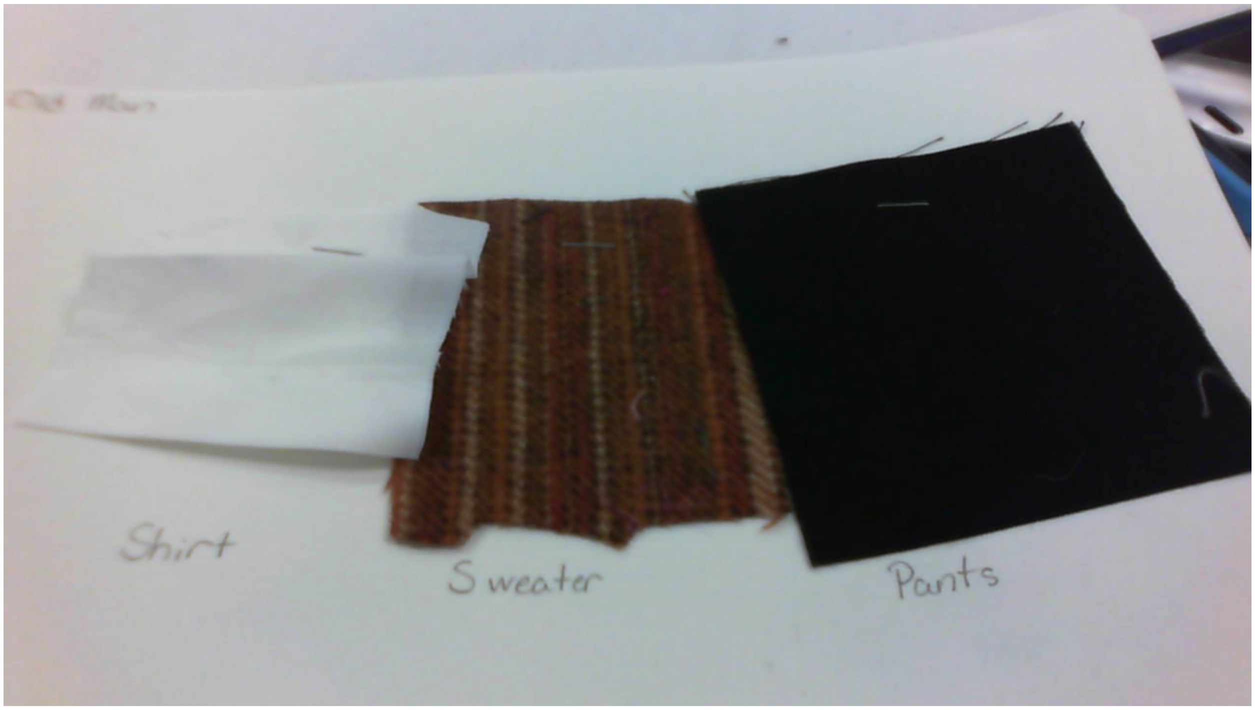
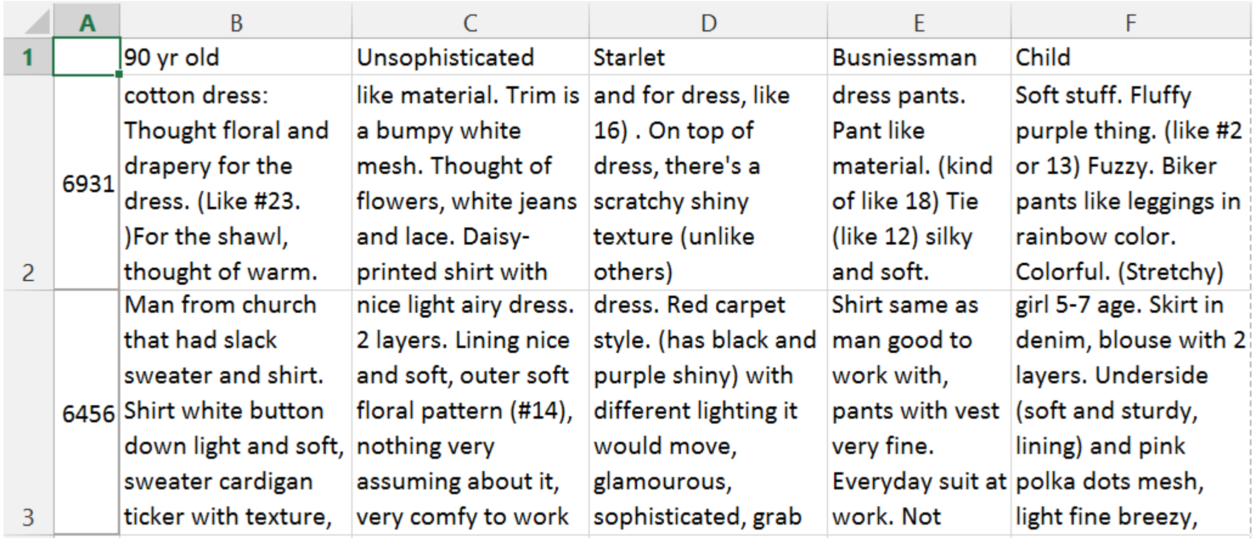


Figure 3.3: One participant's fabric choices for an old man character, based on an old man at the participant's church.

Figure 3.4: Another participant's fabric choices for an old man character, based on the participant's own grandmother, reported to wear bright, flowery clothing.



	A	B	C	D	E	F
1		90 yr old	Unsophisticated	Starlet	Busniessman	Child
2	6931	cotton dress: Thought floral and drapery for the dress. (Like #23.)For the shawl, thought of warm.	like material. Trim is a bumpy white mesh. Thought of flowers, white jeans and lace. Daisy-printed shirt with	and for dress, like 16) . On top of dress, there's a scratchy shiny texture (unlike others)	dress pants. Pant like material. (kind of like 18) Tie (like 12) silky and soft.	Soft stuff. Fluffy purple thing. (like #2 or 13) Fuzzy. Biker pants like leggings in rainbow color. Colorful. (Stretchy)
3	6456	Man from church that had slack sweater and shirt. Shirt white button down light and soft, sweater cardigan ticker with texture,	nice light airy dress. 2 layers. Lining nice and soft, outer soft floral pattern (#14), nothing very assuming about it, very comfy to work	dress. Red carpet style. (has black and purple shiny) with different lighting it would move, glamourous, sophisticated, grab	Shirt same as man good to work with, pants with vest very fine. Everyday suit at work. Not	girl 5-7 age. Skirt in denim, blouse with 2 layers. Underside (soft and sturdy, lining) and pink polka dots mesh, light fine breezy,

Figure 3.5: Both participants' data for the first task.

Task 2: Vest

In this task, since our participants needed to hold and feel fabric, we not only collected their responses, but also collected how they held the fabric. Figure 3.6 and 3.7 show two differing ways designers held and compared different fabrics. One rubbed the fabric in between their fingers, while another draped a fabric swatch on each finger to test and be able to immediately compare the drape.

Figure 3.6: One participant holding the swatch of terrycloth fabric between her fingers to understand the texture. This is a sample of different gestures done by participants to understand the fabric.

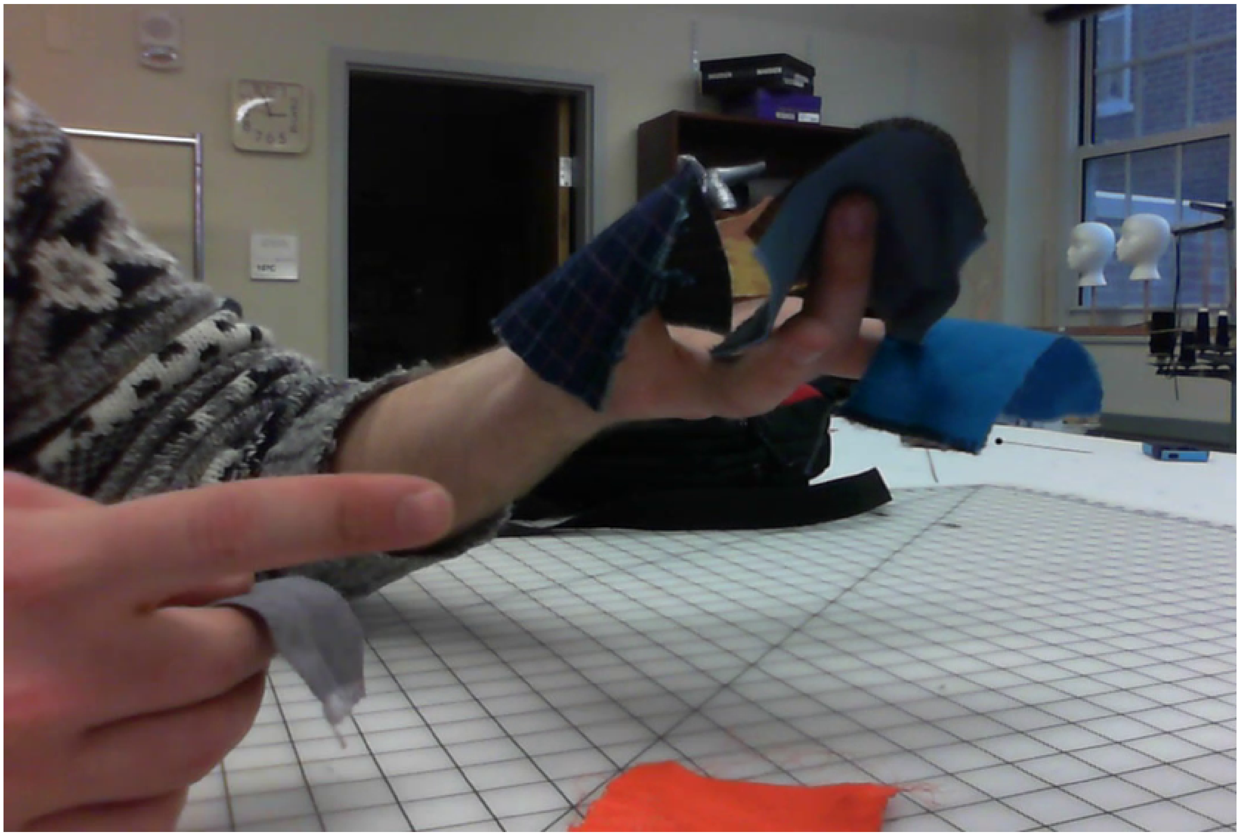


Figure 3.7: One participant balancing a fabric swatch per finger to understand drape, texture and softness.

Fabric-Specific Trends

To highlight the different words said per fabric, table 3.1 shows the different ways a swatch of fabric was described.

Fabric	 1. Chanel	 7. Green-Pink Plaid	 14. Flowers	 16. Liquid
Expert	It's such a rich fabric. It 's , Nice hand(drape). Has *weight.* It is *rich societally and texturally. Kids may read it as old.*	It's rich because it's *silk.* But pair it with jeans and a shirt, and the pattern almost makes it pedestrian.	This is what I expect for *innocent. Like tissue.* Can see through it. The weight, the touch, and how it flows and drapes is otherworldly. *Sturdy.* Nubly. One would totally go for the *bumpy* texture.	It's like *liquid.* If I saw a big piece of this, it's *flowy,* stays and clings on like liquid. Rubbery. More flowy than #12. *Stretchiness* is a factor.
Participant	(6216) Would pick it. As warmth to it, and heavier. *Heaviest.* Warmest. *Like wool Christmas sweater. Like a blanket.* Most blankety.	(6931) Don't like the texture. Almost silky, but the threads are *wonky.* Rough. Don't like the lines. Least soft. Least Heavy.	(8585) Might use for lining of vest. Not outside vest. *Doesn't feel strong* enough (for vest) like pattern. Soft. Not silky. Fray at end when cut. Thinner, flimsy. *Least stiff.* most flexible. least soft but *not rough.*	(6456) more in your face than #10. holds loose. Can't hold form, flimsy. For costume or disco theme. Shiny. can't even feel thread. most movement. Least sturdy, most fine flow, most smooth.
Similarities	Potentially weight?	Silk	"Thin" and "like tissue"?	Flowy
Differences	Cultural references, uses(rich vs sweater vs blanket)	Different properties being described	"sturdy, bumpy" vs. "not feel strong, least stiff, not rough"	Different properties being described

Table 3.1: A sample of the fabric-specific data comparing designer students and the expert, each asked individually. In addition to their raw descriptions, we also included some comparison data as well, associated with comparisons on a separate line. The numbers refer to the fabric numbers, and each participant was identified with a 4-digit number.

To get an understanding of how users grouped or compared fabrics, we encoded all the groupings and comparisons into the chart, figure 3.8 for each comparison and negation descriptor. For ease of reading, green or a “1” encoding represents the strongest of that descriptor, such as the most heavy. The least of a descriptor is represented with the highest number in the column, or in a red color.

For the full data on both the raw text and the comparison data, see Appendix A.4 for further details.

	A	B	C	D	E	F	G	H	I	J
1	Participant	Descriptor	1. Chanel	2. Pink	3. Checkerboard	4. 2-Toned Rose	5. Brocade Rose	6. Orange	7. Green/Pink Plaid	8. Grey Denim
2	6931	normal (used)							1	
3		soft							2	
4		heavy							3	
5	8740	vest for younger character			1		2			
6		coarse			1					
7		shiny			3		1			4
8		weight			3		2			1
9		smooth			2		3			4
10	6216	heavy	1	2						
11		warm	1	2	3					
12		blankety	1							
13		soft	3	2	1					
14		light			1					
15		stretchy	2							
16	0462	NOT soft								1
17		tightly knitted								2
18		soft								4
19	8585	NOT stiff			1		1			
20		strong			2		1			
21		flexible (oppose stiff)			2		3			
22		soft			2		2			
23		NOT rough			1		1			
24		NOT silky								
25	6456	less in your face								
26		sturdy								
27		fine flow								
28		smooth								
29		movement								
30	1005	color going well								1
31		NOT smooth (oppose rough in texture)								1
32		NOT rough								
33		shiny						1		2
34		eye-catching						1		
35		coarse					2	1		3
36		smooth movement					4	5		3

Figure 3.8: Chart of each participant's response when asked to compare or group different fabrics based on any description. Green or 1 exemplifies the most from the descriptor, such as most soft, while red or a high number represents the least of that descriptor. Descriptors that are negations also count.

Overall Trends

To get an initial sense of overall trends, we cleaned up the data, extracted root words from all the descriptors and generated a frequency chart of the top nine most frequently used words, shown in figure 3.9.

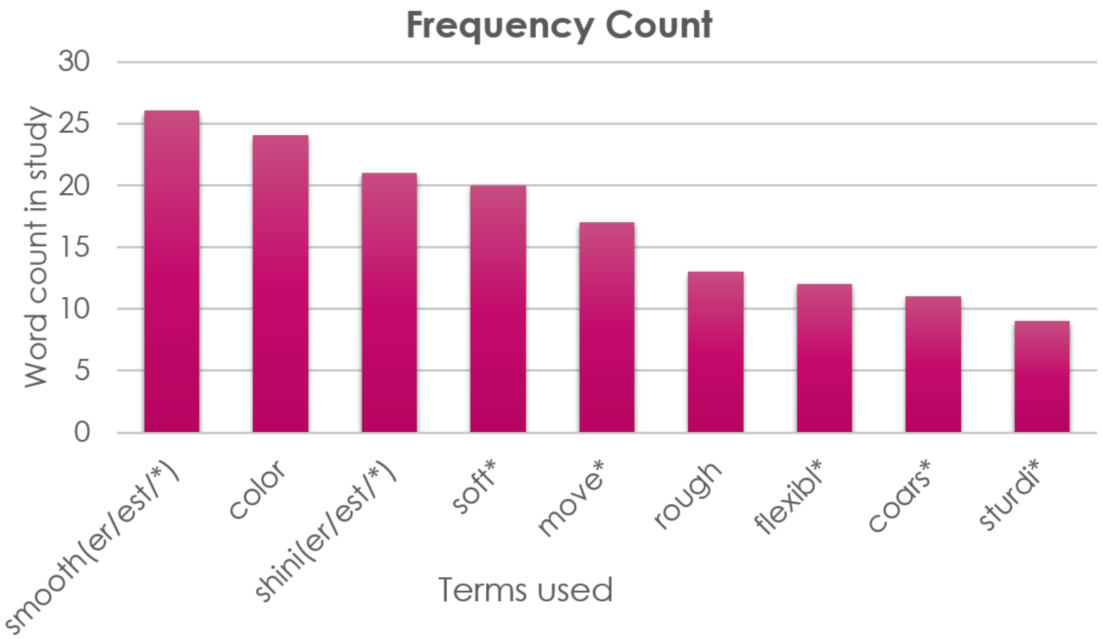


Figure 3.9: This frequency chart shows the most frequently used root words during the study. For example, smooth, smoother and smoothest all count for the same word.

To drill down into the meanings and associations for each of these words, figure 3.10 shows the top word associations for the 5 most frequently seen words, with over 50% co-occurance probability.

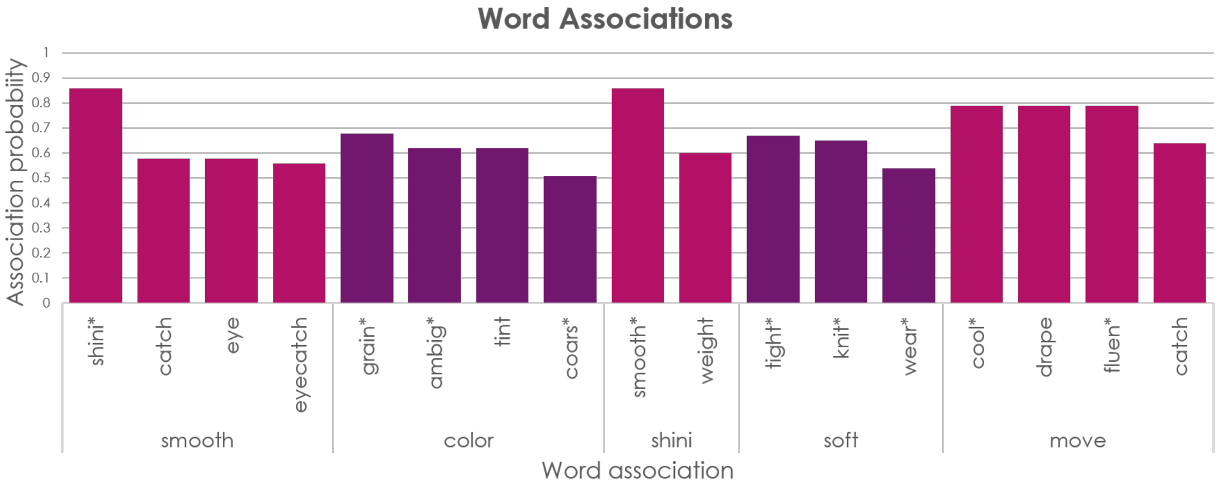


Figure 3.10: Association chart showing which words are associated with the top 5 most frequently used words, with over 50% co-occurance probability.

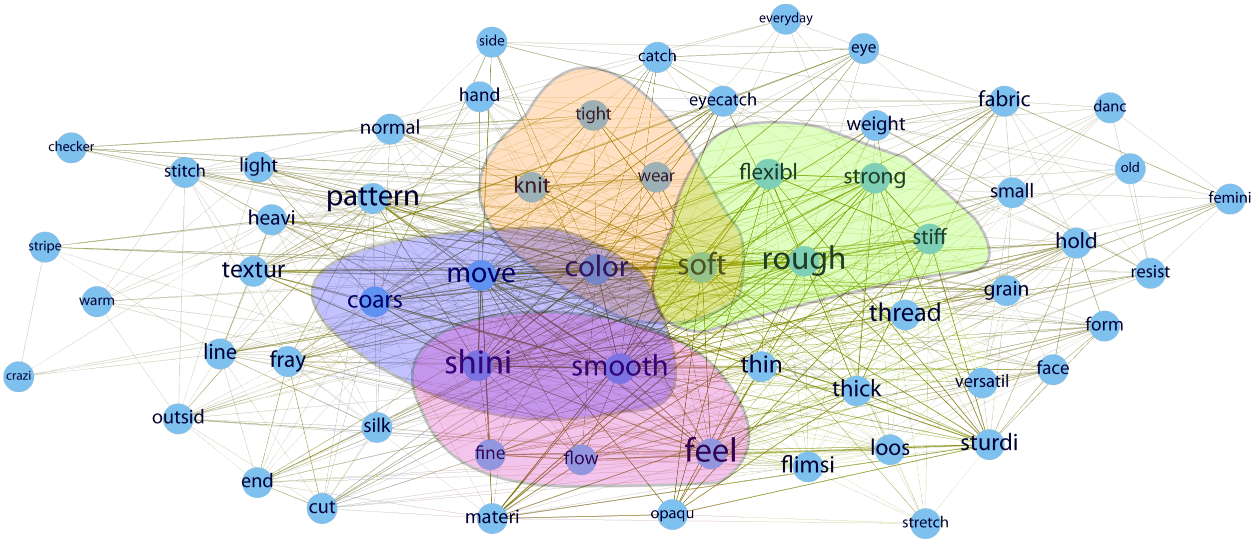


Figure 3.11: Network of co-occurring descriptions for fabric in our preliminary study of how designers describe fabric, in root words. Larger text represents more frequently used word, and clusters represent the top 5 highest ranked words in each topic in the topic modeling analysis. The nodes were distributed in position for visibility only, so the projection bears no relevance in the analysis.

Figure 3.11 is an overview of the results of our descriptor ambiguity study. This figure shows a graph of words, connected by more solid lines if the word co-occurrence is stronger. Colored clusters group the most important words in a topic when performing LDA analysis, with 4 topics.

This network makes word associations, such that one designer's "soft" may be opposing "rough", or "stiff". "Soft" could also mean a visual property, with it's connection to "soft". In addition to the "soft" ambiguity, words like "shini" and "smooth" are both associated in one topic with color, implying a visual property, and in another topic with "feel", relevant to textural properties of the fabric.

3.1.9 Study Discussion

Two major points were salient in this analyses that affected our results and how designers describe fabric.

Ambiguity in descriptor terms

The first observation is ambiguity in the words themselves, such as "soft" being grouped with both "color" and "rough", implying both a visual and textural property, respectively. Thick and thin, despite being opposites, may also have other meanings beyond fabric thickness, such as yarn thickness. Ambiguity is also found in comparing expert to participant comments in table 3.1, where the liquid fabric is both "flowy" and "flimsy", by the expert and participant respectively. Between these participants, we also found different properties being described, such as the liquid fabric's (#16) stretchiness mentioned by the expert and not by one participant.

Cultural and societal interpretations

The cultural and societal interpretations of each of the designers also carries over in how the fabric is described. In table 3.1, the Chanel fabric (#1) being described as both rich and like a christmas sweater, by an expert and a participant respectively, reveal a glimpse into a designer's individual worldviews, experiences and perceptions over the fabric itself. Even the liquid fabric (#16) was described in different ways, with one designer associating it with liquid while another is more for costume or disco themed.

3.1.10 Study Conclusions

Given the ambiguities in the descriptors themselves, the potential lies in how to represent fabric when the designers are unable to feel the fabric directly.

Many of these descriptors in figure 3.11 and in table are not overly technical or complex of terminology, even with our expert describing fabric with common words like “liquid” at the table 3.1. While our designers, including our one expert, could simply have had good communication skills, prior work showed that everyday participants did not understand some expert words [59]. Non-designers use fabric descriptors to understand clothing when doing online shopping [32], so these descriptors are valuable to everyday people.

Feeling fabric is a common embodied experience, so comparing prior work and the resulting descriptors from our study encouraged us to explore how everyday people’s descriptors compared to these descriptors and how did that affect the ambiguity of the dataset.

3.2 Exploratory fabric study for general

The prior study showed that ambiguity exists between the ways that different designers describe fabric, but we were also curious about the ways that everyday people describe fabric. We wondered whether there would be similar or different kinds of ambiguities in this group. We also wanted to increase our vocabulary of descriptors for our system.

Since we wanted to increase our quantity of fabric descriptors, we chose to crowdsource our fabric descriptors by conducting a similar study with everyday people. We chose our location to be ICAT Day, a day where projects relevant to the Institute of Creative Arts and Technologies (ICAT) at Virginia Tech are showcased.

This work had a booth where we showed fabric samples from the prior study, where visitors could choose to participate in this study and get rewarded with showing results from the prior study. If visitors were either ineligible or chose not to participate, we only showed them the results from the prior study.

3.2.1 Questions

Similarly to the prior study, our research questions were:

1. **RQ1: what kinds of adjectives and *properties* lie in these fabric descriptors by designers?**

2. **RQ2: What kinds of *ambiguities* lie in these fabric descriptors by designers?**

3. **RQ3: How can we *design* interfaces with standard interface toolkits to help designers explore and understand material remotely?**

The third research question was the only addition compared to our previous study. This question helped guide our decision on whether to merge the descriptors for our system between designers or non-designers, and helped us deduce whether we needed to further specialize or generalize in future studies.

3.2.2 Study Design

This study was an open-ended study with less control than the prior one, but we were concerned about the possibility of participants biasing the responses of other participants, such as by parroting or agreeing with another participant's words.

Another scenario we wanted to avoid was showing the graph while a new potential participant approaches the booth, overhearing our discussion of the results and getting biased from the fabric descriptors heard.

To prevent these biases, we only allowed visitors to participate if they approached the booth either individually or as a pair, with no prior participants at the booth at the time. This limitation narrowed our pool, since visitors came to the booth while the moderator was talking to a participant, but we chose to decrease our participant numbers to get higher quality results.

3.2.3 Task

Similar to the task in the prior study, we asked participants to describe a set of fabric. We had a set of 4 fabrics randomly selected per participant to compare. After the participant felt each of the three fabric samples, we asked the participants to describe each fabric individually. This task was an abridged version of the previous study's second task, and we only asked about 4 fabrics to accommodate for the short time that visitors would want to stop by a booth at this public event.

3.2.4 Participants

Visitors of this event were both internal and external to the university and to the local community. Our participants were a subset of the visitors, from 18 to 64 years of age. We surveyed a total of 7 participants; the quantity was limited by the aforementioned bias-prevention measures in our study design.

All but one participant had experience with fabric, while all participants knew how to sew. One participant had 11 years of quilting and sewing experience, while another had 1 year of embroidery experience. The remaining four participants had sewn on occasion, such as for altering and fixing clothing.

3.2.5 Data Collection

To address our questions on ambiguity, we noted the participant's background with fabric and recorded how they described the different fabrics. We had a **pre-questionnaire** with one question asking about previous experiences with fabric. This questionnaire was conducted verbally and filled out by the moderator.

We captured the participants' responses through the **moderator's notes**, and, for redundancy, **audio recordings** that were later transcribed. Similarly, like in the prior study in section 4.2.2, we cleaned up the data and conducted a series of frequency, word association and topic modeling analyses.

3.2.6 Relevant Equipment and Software

The same equipment and software from the prior study was used in this study. Please refer to section 3.1.6 for further details.

3.2.7 Procedure

First, the participant was asked about their experiences working with fabric, specifically what they have done and for how long. Then, the task began. After the task completion, the participant was shown figure 3.11, comparing their answers to the graph, and was also shown a prototype version of our fabric simulation system, which we will describe later in section 6.1.

3.2.8 Results

Participants collectively said 298 words to describe fabric, with 146 descriptors extracted and after cleanup, and 85 unique descriptors. Participants described each fabric on average with 5.2 descriptors.

Due to the size of this dataset, frequency charts, associated word charts, and Latent-Dirichlet Allocation do not apply to this analysis. Figure 3.12 shows a summary of the results, processed exactly like the prior study, without groupings since the small data size.

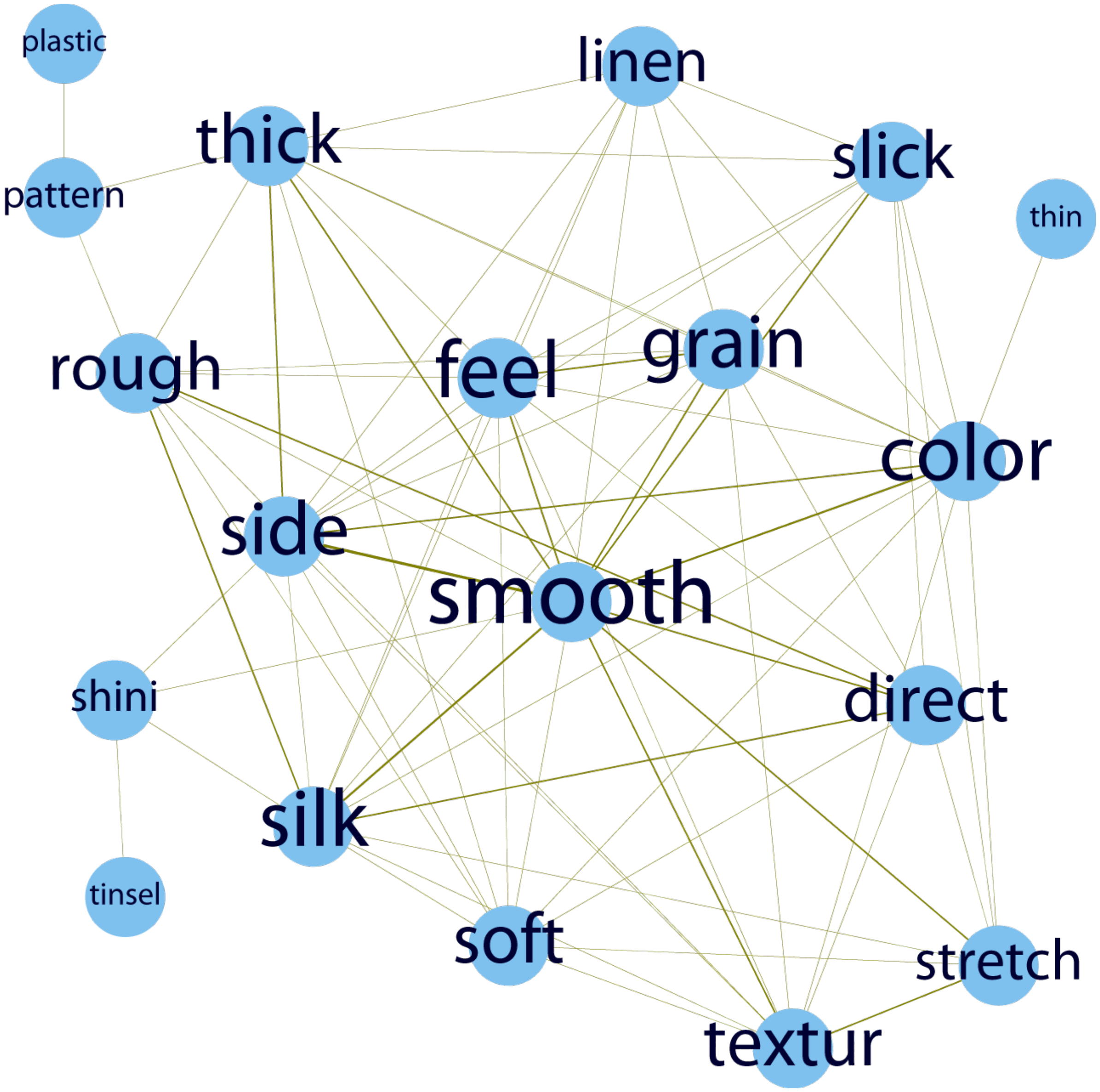


Figure 3.12: This is a co-occurrence graph, in similar style to the prior co-occurrence graph, where descriptors shown have been used more than once. The opacity of the lines indicate co-occurrence, not node distance.

3.2.9 Study Discussion

As in the prior studies, descriptors can be connected to various different interpretations. In figure 3.12, “smooth” may mean a textural feel, with its association with “grain”, “textur” and “feel”, but may also be associated with the drape of fabric with its connection with “slick”. “Soft” remains connected to “smooth”, implying a textural quality, while also being connected to “color”, though neither as strong as the prior study.

3.2.10 Comparisons Between Audiences From Prior Studies

Since the second study was more brief than the first, the participants had far less to say about the fabric pieces than the first study, with the first study giving 1022 words compared to 298 words, and each response giving 12.1 descriptors versus 5.2 descriptors, with the everyday participants giving less than half of descriptors than the design students. Given these disparate differences in datasets, it wasn’t appropriate to compare with statistical methods. We instead chose to compare by descriptor usage and by fabrics described.

When comparing the results of the second study (figure 3.12) with the the co-occurrences graph in the first study (figure 3.11), several commonly-used popular words are apparent, including “soft”, “color” and “smooth”. Such words also tend to be connected together in similar ways. Indeed, when we added both study datasets together, but the addition did not change the co-occurrence graph much.

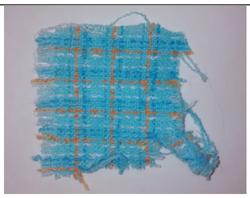
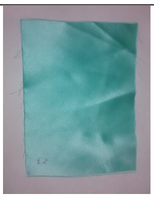
Fabric	 7. Green-Pink Plaid	 9. Blue denim, light back	 14. Blue, orange stripes	 16. Teal Shiny
Costume design students	(6921) Don't like the *texture.* Almost *silky*, but the threads are wonky. *Rough.* Don't like the lines. *Least soft.* Least heavy.	(8585)*Sturdy but not stiff*, that can move with the person, flexible, *thick enough*, opaque, don't like look but like material. Most *soft*, not rough	(6921) *Outgoing, crazy. For a crazy person.* Colors are funky. *Silly.* At goodwill. Soft. Have lines. Don't like this kind of stripe. Most soft. Mid-heaviest.	8740: For more eloquent setting. Thinner and *shinier.* Would be a vest for *dance, ring dance.* Threads are smaller. *Smoothest.* Too thin. Like women's blouse. Feels like *feminine fabric.* Can run finger through it with no resistance, compared to #5. Least *weight.*
Everyday people (1)	Looks like silk but it's *not silk.* It is linen. *Gritty.*	Really like this one on black side, *really smooth*, warm texture to it on the blue side.	*Soft.* Feels really textile. Can feel individual threads. Feels *loose.*	Silk, smooth, very *smooth.* A sheen or *shine* on one side.
Everyday people (2)	...I can't come up with the word I want. It has a distinct grain, relatively *smooth* but you can still feel the texture. *Silky in one direction and in another. It's more rough*, based on the grain.	Two sides are very different. Black is *smooth, slick*, and the blue side is more linen. It feels like it's a *thicker coarser grain.*	*dishcloth*, kind of *stretchy* and *soft*, textured	*smooth* kind of *silky*, a little *stretchy*, seafoam green
Similarities	Mention silk, rough	thick, smooth	Soft	Smooth, silk, shiny
Differences	silky vs not silk, smooth vs rough?	Properties described(soft, slick, stiff)	Uses (for crazy person, dishcloth), properties(stretchy, loose)	Cultural references (feminine, event context), properties (stretchy, weight)

Table 3.2: A sample of the fabric-specific data between everyday participants and the design students, comparing the first and second study. Italic words highlight differences and similarities in descriptors between the participants.

To highlight the different words said per fabric per audience, table 3.2 describes the different ways a swatch of fabric was described.

For fabric #7, the designer and everyday people noted how silky, smooth, rough, or neither the fabric was. Texturally, some thought it was like silk, others unlike silk. The second everyday participant noted how this fabric was smooth in one direction, but rough in another. Thus, if smooth were meant to be used as a texture, this fabric may be correctly (yet contradictorily) both smooth and rough.

The novice designers noted different properties than the everyday people, such as drape for fabric #9, and weight for #16. In addition, the designer added a deeper context for their perception of the fabric, such as the kinds of people wearing it (crazy person, rich), the garment type (blanket, blouse), and other contextual associations (feminine fabric, at a dance).

While the two datasets are similar, we found some differences due to expertise, that may not necessarily be ambiguity. For example, everyday people were describing fabrics as a “knit”, referring to a specific construction method [51], incorrectly.

Everyday people used descriptors that may not be entirely accurate, precise or correct, by using words that have a a measurable or objective meaning. Such incorrect usage of words adds more ambiguity to these descriptors. Despite potentially incorrect usages of specific words that have an established meaning, describing something *like a knit* is certainly more open to interpretation than asserting that a particular fabric specific-style knit.

We acknowledge that, unlike other technical topics, everyday people are familiar with fabric and have developed their own set of words around fabric since they were young. This existing relationship presents interesting sets of descriptors, because these descriptors have been collected with a context in mind. Nearly every person is familiar with fabric. But, garment designers see fabric as a means to communicating a concept or idea, so their understanding is quite different. It is not a lack of knowledge between these groups; rather it is a spectrum of understanding, which makes both descriptors compelling for study.

3.3 Implications for Design

3.3.1 Nature of Ambiguity

As these studies show, people, either with clothing design experience or without, all use different descriptors with different meanings. One person’s “thick” could be another’s “heavy”, or both could be different descriptors for some separate property not explicitly identified. Additionally, each could be describing completely different properties as well. Even potentially-opposing words like “thick” or “thin” may each apply to different properties of the fabric, such as a thin thread, but a thick fabric.

Given the potential complexity of any set of words, and that fabric and clothing are something that everyone has had experience with, generating a taxonomy or educating others on the existing taxonomies will not be sufficient. It is indeed challenging to decide whose definition of "thick" is more correct than others, even if we had a panel of experts judging. Morville [43] quotes a patriarch of Buddhism noting that "words...can be likened to a finger. The finger can point to the moon [but] the finger is not the moon. To look at the moon, it is necessary to gaze beyond the finger. " [43]. Words like "thick" and "thin" serve to "point" to the fabric, and this work posits that there are multiple words pointing at the same fabric.

Linguistic data mining techniques may help us to understand these complexities, but mandating a standard or a hierarchy through these techniques may produce an unusable system, because of the complexities and ambiguity that accompany these descriptors. The studies may change to try to capture as much of the baggage that is included in each word, but even a user may not immediately be able to unpack all related words. A graph may not fully capture the entire complexity of these words. While further work may explore how to best capture these complexity in the appropriate data structure, the solution is not simply a technology-specific concern, but rather needs to be studied holistically with people, fabrics, and the system revolving these two. After all, terms that imply some ambiguity like *abstract classes* are defined in computer science introductory books as a super class to call methods from more defined classes [6], not necessarily beyond the defined.

Opposing or differing descriptors are equally important in helping a designer understand an individual fabric. A fabric can be both "thick" and "thin", even if it is described by a single person.

Since fabric needs to communicate some message to an audience (whether winning over an audience in fashion design or communicating a character in costuming), a piece of fabric may mean different things to different people. Understanding a set of possibly ambiguous or diverging descriptors gives a designer more information on what that fabric communicates.

3.3.2 Operationalizing Ambiguity

It's a challenge to focus on how to capture these human experiences of fabric, combine them in a meaningful way, and provide it all in an interface. The first step was to better understand ambiguity, in what forms it takes, and operationalize a definition that guided us for studies and interface designs moving forward.

While there are many definitions of ambiguity, more discussed in section 2.3 in Chapter 2, In terms of this thesis, the definition that helps us the best, especially given the different ways to understand materials, is MacKay's definition: "any stimulus pattern which is capable of two and only two distinct interpretations"[40]. This definition encompasses that a broad interpretation of a stimulus, whether it's someone else's descriptors, an image of fabric, or the actual fabric itself, and the different stimulus that can spur ambiguity are key pieces in designing systems relevant to ambiguity. This definition also encompasses where something is not clear, or that both interpretations are opposed to one another too.

We chose to capture these ambiguities with respect to a co-occurrence graph, to see the relationship between interpretations, supported by prior literature capturing ambiguity with relational networks [19]. Since multiple interpretations describe the same fabric, they have some connection with one another. Our materials are diverse, so ideally the interpretations would also be diverse as well. If all of our samples were made of cotton, for example, we anticipated that we would get many interpretations connected to the "cotton", and that connection was only a function of the fabrics themselves and not inherent to how participants described fabric in general.

3.3.3 Ambiguity on the word level

In these studies, we have asked people to describe fabrics, to obtain the most salient properties, and found a series of ambiguities in interpretation. We hoped those descriptors helped capture the experience of fabric, and what we got ranged from a word, to full sentences and anecdotes.

Starting with the smallest unit of measure, we studied ambiguity at the word level, which allowed us to find correlations and connections between different words, that we can use in visualizations, searches, and more.

At the word level, we have sufficient quantity of ambiguity to study how to design computational systems. From Noam Chomsky's book "Aspects of Theory of Syntax", The particular category of ambiguity is lexical, or semantic ambiguity, where words with the same grammar can have multiple meanings[10]. An example would be: "a thick fabric", where it could be interpreted that the fabric thick in thickness, or heavy, dense, some combination, or all of the above.

If we had studied ambiguity on the phrase level, we would be able to capture more of the context, and get a better sense of the ambiguity. But ambiguuities at the word level contribute to the phrase level. By studying ambiguity at the word level, we are studying the smallest unit of description that participants have given us. In some senses, it's practical to study at the word level because of the nature of the data we received.

As an initial work, these studies helped us the word-level ambiguities, and those ambiguities provided enough information for us to design to support ambiguity. Past this study, our designs support both word-level and phrase level ambiguity, with the users using words to give access to phrases.

While future work may exclusively target studying ambiguity at the phrase level, the word-level provided a useful scope for these studies.

Impact of correctness on ambiguity

Studying designers and everyday participants allowed us to see how would the role of correctness fit into these more ambiguous domains. There are multiple ways to separate ambiguity from incorrect word usage, with the simplest solution being to restrict descriptors to only experiences audiences, to have expert validation of the descriptors, among others. But, since these words contains a baggage of other descriptors and contexts associated with that word, one's usage of the word is not necessarily better or more correct than another. Words like "knit" may be associated to comfort fabrics or ones that remind one of knitting needles. "Like a knit" describes similarity, while "2 x 2 knit" may be more precise, and thus may be a descriptor the most subject to being correct.

One way to better distinguish between simply incorrect word usage from the baggage may be to ask the participant to define and identify similar words for every descriptor used. Not only would each word in a definition need its own definition, resulting an a long exercise trying to unpack that baggage, but also a challenging exercise to objectively define what explanations and descriptors are valid. How would the context from "Christmas sweater" be more or less correct than a "rich" fabric?

These usages, whether they stem from proficiency, context and experiences, or incorrect usage may be important and valid. Given our findings and the nature of the discourse associated with fabric and other touch domains, we do not recommend culling potentially incorrect data and rather recommend designing technology to display conflicts in data, and let the designer decide what information is helpful.

While it is worthwhile to collect more words and increase our participant sizes, our studies show that a portion of the population, outlier or otherwise, whether everyday people or novice designers, are not served by prior taxonomies [30, 3], regardless of whether the responses may be incorrect or noise. These challenges present compelling opportunities in designing for domains that present these ambiguous descriptors.

3.3.4 Interface Designs

Computational systems for designing with fabric need to take the opportunity to design with ambiguity and display it prominently, and not simply be adversarial with it. There are various different research and design opportunities in ambiguity. While there will be concrete identification of fabric when building these computational systems, the access to it (And the synthesis of new things from it) must honor these ambiguity and the discourse of practice.

As a brief example of ambiguity championed in designs, figure 3.13, where a search box can show a set of the most associated words. Those words may be seen as similar or different terms, like searching for "soft" and seeing "heavy" pop up. But, it leaves the user to decide on how they interpret those words, and what should or should not be included in the query.

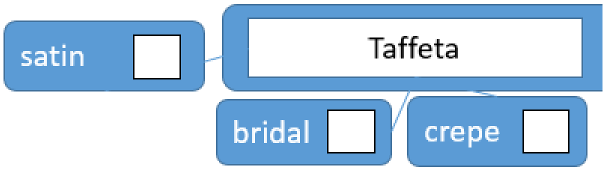


Figure 3.13: A search box that, when typing “Taffeta”, would show other associated words to include in the query. The user can add it to the query by selecting the checkmarks.

Understanding ambiguity can steer us from interfaces based on categories and taxonomies, to conversations. Instead of a goal-based system to help find fabric, a more conversation-based interface can take advantage of these descriptor collections to indirectly facilitate dialogue between a designer and people that have collectively felt the fabrics. Such interfaces may use multiple representations to maintain a dialogue with the user.

To see more of our system designs and how they have evolved, please see Chapter 6.1, and the evaluation, in Chapter 7.

3.3.5 Practical Implications

In addition to interface designs, this study has implications in current practices in exploring fabrics, as brick-and-mortar fabric stores slowly close. These designs that emphasize what others have said, in parallel to visual information, help designers make better decisions on fabrics when remotely purchasing.

These studies imply that places that discuss fabrics, whether it’s reviews of fabrics, or using fabrics for a project, may be a great resource for exploring fabrics. Places that highlight what people have done with fabrics, like Pintrest, may be an effective resource for designers to negotiate what a fabric would be like.

The kind of project also determines when can these kinds of user-driven and visual information can help. If a designer is looking for a specific kind of fabric, fiber content, visual look, etc, such feedback may be less helpful than a project that is earlier in the design process.

3.4 Conclusions

For the reasons above and to keep the scope in place for the research, we chose to investigate and collect more words with people, to get a better sense for the nature of ambiguity in the work, and how we can apply it to technology designs.

We explored the ambiguities that lie in describing fabric, from the perspectives of both the garment designer and the everyday person. We conducted studies in differing settings that asked multiple people, from non-designers to expert costume designers, to describe a series of distinct fabrics with varying textures. We found that the descriptors used were unclear, sometimes describing multiple properties or contradictory between people. It is not immediately clear whether two potentially similar words mean the same thing to different people, describe the same property, or even describe separate properties altogether.

Taxonomies are useful tools, but may not be suitable for handling ambiguity. To design systems that revolve around fabric and other topics with unclear or contradictory information, we have identified opportunities for the design of systems that do not resolve, diminish, or hide ambiguities. Since all descriptors capture something about fabric, we posit that the design for systems involving fabric should champion, highlight, and take advantage of the ambiguity in these descriptors.

To understand these descriptors better, our next studies leverage crowdsourcing techniques further to expand our participant pool to capture even more descriptors. With a better understanding of these descriptors, we better understand the similarities and differences between designers and non-designers in relation to fabric, an intimate medium with which everyone is familiar. By better understanding the descriptors that everyday people and designers use, we can better design interfaces in domains where visuals may be misleading, and descriptors may be contradictory or ambiguous.

We have encountered these problems of ambiguous description in our studies with fabric, a material we experience everyday. In a similar problem, how would you describe the ocean?

Chapter 4

Media Crowdsourcing Studies

4.1 Crowdsourcing Descriptors: A Comparison of Fabric Descriptors from Live and Crowdsourced Participants

In order to further understand the ambiguities from prior studies, it is imperative to get more descriptors from both designers and everyday participants. Crowdsourcing the descriptors is promising for because of how diverse the crowd is, yielding different interpretations and experiences to the same fabric.

Since the crowd is unable to remotely touch real fabric, the crowd needs mediated experiences and digital representations of the fabric. Designing these mediated experiences is an important challenge for performing open-ended inquiry on the crowd, especially on topics that are context-driven and have no one correct answer, like touch.

4.1.1 Research Questions and Goals

Our goals were to compare:

1. *Real-world versus mediated interactions.*
2. *Real-world vs. crowdsourced descriptors for open-ended short responses on tangible qualities.*
3. *Responses from smaller-sized fabrics (3" x 3" fabrics versus 10" x 10" fabric square from Real-world and crowdsourced participants*

We sought to push the boundaries of what could be learned from the diverse crowdsourcing community by focusing on open-ended questions that have no wrong answer. Additionally, by focusing on tangible qualities, ones that are physical and contextual, make this inquiry more diverse. If these comparisons do not yield significant results, then the crowdsourcing community may have some prediction power. If there are large differences between the audiences, then tangible open-ended questions may be a limitation to what could be asked in the crowdsourcing community.

While designing this experiment, our expert suggested to obtain bigger swatches than the smaller size we were using, to better make more sense of the fabric. The drape of the fabric is harder to deduce if the fabric is small, compared to a longer or bigger piece of fabric. In looking further, different fabric industries use different swatch sizes as well, from smaller swatches that are a piece of a whole, to bigger swatches used as production tests [61]. So, we wanted to evaluate more concretely whether sizing made a difference in what people said.

To investigate these queries, we compared the quantity of descriptors along with descriptor differences between these audiences.

4.1.2 Experimental Design

We conducted an online and live version of the same study, collecting descriptors used to describe fabrics, varying on type and size.

We hypothesized that the live participants hold fabric would describe more and in quantity than the crowdsourced participants, especially since the live participants can more easily discuss more about the fabric beyond a screen. Additionally, we hypothesized that fabric size would have some impact on what people would say, since the bigger fabric sizes may reveal more about the fabric than smaller sizes.

Tasks

All participants performed two tasks: describe five fabrics, and rate or group the fabrics. Participants first described the fabric individually, one by one. Due to prior experiences of performing the fabric-describing task in public events, we generally got three responses, and required that participants gave at least 3 unique descriptors for this task. Participants then ranked the fabrics based on descriptors, such as the most “shiny”. The descriptors were randomly selected from the first task.

For online participants, fabric was in the form of a video, being manipulated by a pair of hands. Such manipulations include stretching, draping and waving, among others. The gestures have been pre-approved by a costume expert. The tasks were accomplished by a survey with embedded videos.

The live participants did a live version of the tasks with real fabric first, following with the online version of the tasks. The live participants also compared the online versus live versions, so we can better understand how the different representations of fabric (video or real) affect their understanding of fabric.

In summary, to account for differences between the online and live version, we had three conditions; We had a live participants describing with real fabric, the same live participants describing fabric on video, and crowdworkers describing fabric on video. For the live participants, since they did both the online and live tasks, it's within subjects design for the live participants.

Fabrics

Participants described randomly selected fabric varying in 22 different kinds, from velvets, quilting cotton, to silk.

Since our expert advised us that size may affect responses, we held a pilot study that asked participants in a public event to describe fabric and share their thoughts on size. In brief, all seven participants thought size was relevant. Influenced by this pilot, we cut fabrics into two sizes: small, a 4" x 4" square, and large, a 10" x 10" size square. Four fabrics were only available in a small size. We also had participants have different distributions of varying sized-fabrics, bucketed into six conditions, from 0 small fabrics to all 5 small fabrics.

With respect to fabric sizes and and types, this study is between subjects, since each participant saw different fabrics out of the set, and had a different distribution of sizes.

Video Design

Given that this video is meant to highlight fabric briefly, we did not expect users to look at a longer video. So, we kept the video at maximum one minute.

We got advice from a design expert on what kinds of properties that needed to be highlighted in a video about fabric, and we iterated with her on the kinds of gestures to represent the different properties of fabrics. Figure /reffig:gestureVideo shows properties of fabrics, and their corresponding gestures.

To be sure that we did the gestures uniformly, we also had a protocol of how to accomplish each one of the gestures. We maintained the same distance between the fabrics and the camera, with a set duration dedicated to each gesture. We did all waving and moving gestures moving the fabrics with a similar kind of sway. As a guide for the gathering motion, We targeted gathering the fabric in approximately the same amount as shown in these fabric swatches in figure 4.1. The samples were provided by the expert, originally built to see how different fabrics gather.

Property	Gesture
Front and back of fabric	Show both sides of fabric
Movement	Waving the fabric with the front side centered, and repeat for the fabric on the side.
Drape	Drape fabric swatch on wrist on the tips of middle and index finger. Then lift fingers alternating.
Stretchiness	Stretch in the warp, weft and diagonal directions
Gather	Gather the fabric by hand and wave the fabric like with the movement gesture.

Table 4.1: Table mapping the fabric properties, to gestures showing those properties on the video.

Figure 4.1: Samples of different kinds of fabrics gathered, done to get a sense of how different fabrics gather.

Participants

Live participants were garment designers of all expertise. These participants were recruited from costuming and fashion design networks locally and in big cities. The minimum requirements were to have sewn or built with fabric. For their expertise, we paid $9 for the entire experiment, with the study lasting from 26-40 minutes. The amount was a function of minimum wage in east-cost metropolitan areas.

We have chosen to do the online condition on Amazon Turk, to get a diversity of descriptors and responses. Participants needed to be in the United States and have a HIT response rate above 95% rate. The online study lasted on average 15 minutes, and we paid $2 in proportion to a quarter of an hour relative to the hourly wage in our state.

Data Collection and Analysis

For the live version, we collected all data by *verbally asking* participants to describe each fabric, *recording* audio, and *transcribing.* To collect overall comparisons and impressions, live participants also were *interviewed.* We also asked live participants about their prior experiences with fabric.

The online version of the study had a *survey* with embedded videos of fabric, and they described it with 6 text boxes, with one descriptor word or phrase per box, twice the required amount. Instead of grouping and rating real fabrics, online participants rated fabrics based on a 5 point scale for six randomly selected descriptors.

We started our analysis with collecting all unique descriptors per group, between Turk workers, live participants holding real fabric, and the same live participants doing the Turk worker tasks. This analysis helped determine whether the differences were between participant groups, or how the inquiry was mediated online.

We piped the data to the Statistical package R, to do data cleaning, and analyze the dataset. All data was stored in a table where the columns are the individual fabric, and the row is the participant. We cleaned out the dataset by removing filler words, verbs, and other words that were not helpful in the tasks. We re-labeled all color as one label to categorize the data, and collected all words with similar root words together, such as “shinier” and “shiny”counting for the same word.

We analyzed the data with respect the number of descriptors per group, and a comparison test to see whether some words were more present in one group than another. We also conducted a non-parametric CHI Squared test, with degree of freedom = 1 for 95% percent probability on each word comparing between both groups.

4.1.3 Results

Figure 4.2 and 4.3 on the next page are our most prominent results with respect to the data. There were no notable results for fabric sizes, the ranking of fabrics nor for specific fabrics.

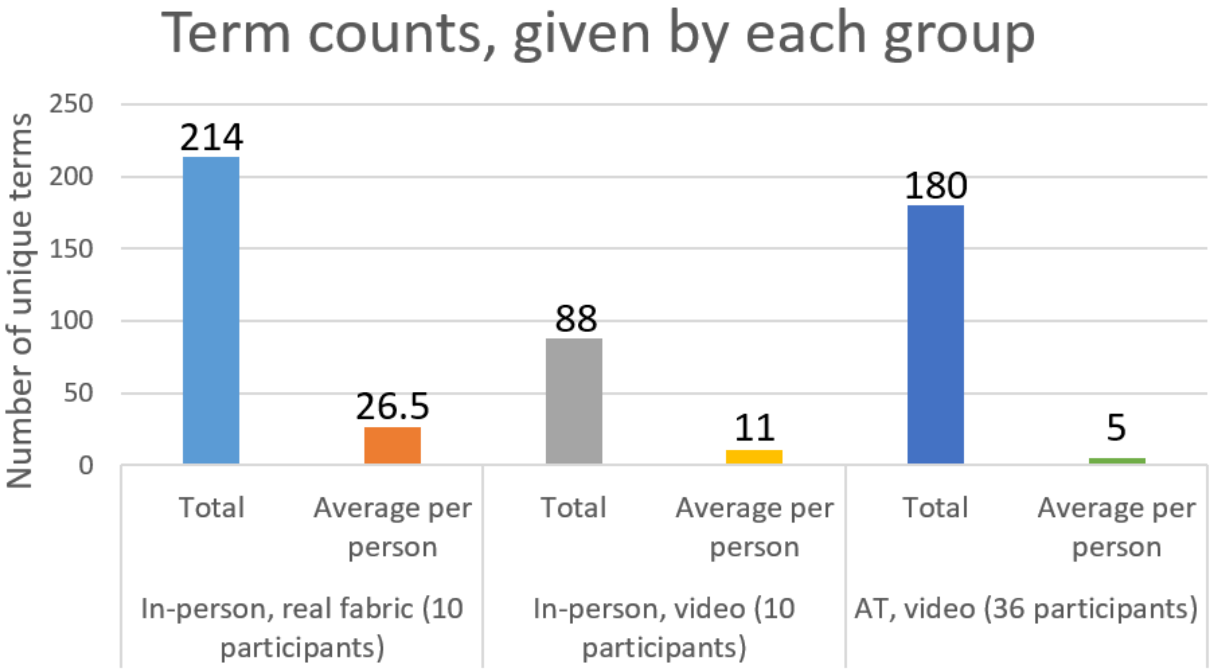


Figure 4.2: The graph outlines how many unique descriptor terms were given with respect to each group, for both totals per audience, and the average per person.

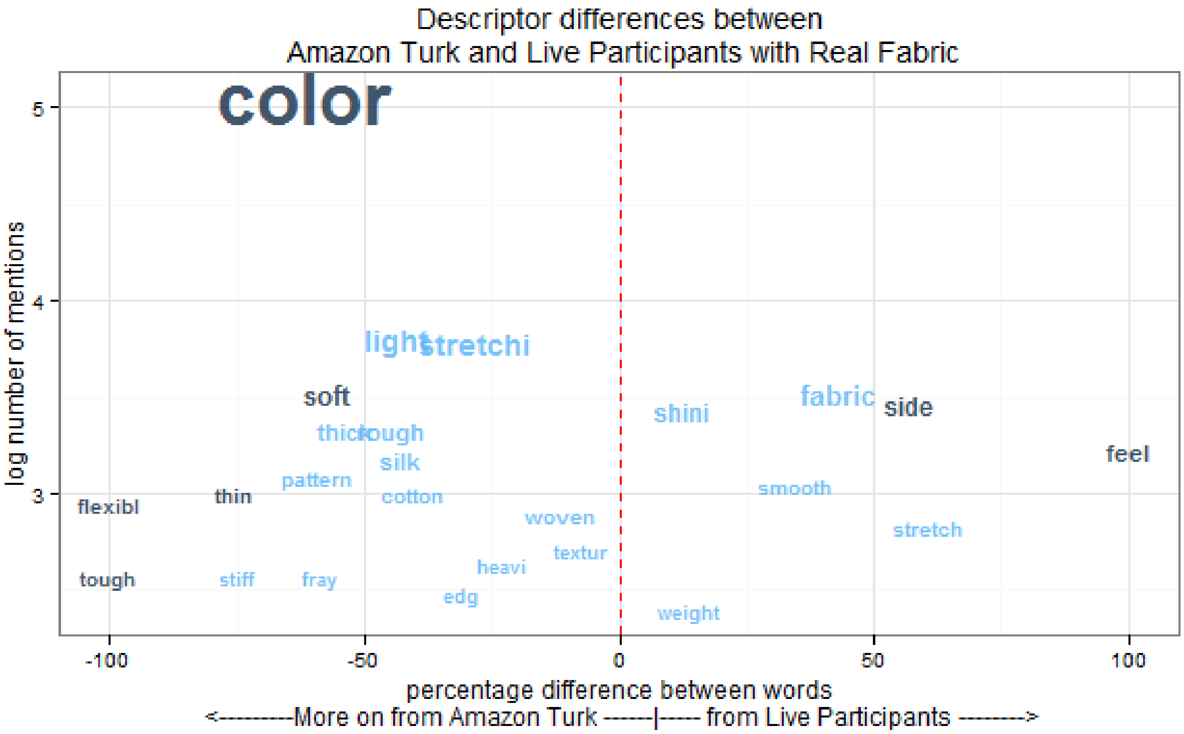


Figure 4.3: The plot shows descriptor differences between the Turk and live participants describing real fabric. Words on the left were used more by Turk workers. Dark blue words are significant to p > 95%. Text size is relative to frequency of use.

4.1.4 Descriptor Counts

We calculated how many unique descriptors were present in the data. Figure 4.2 shows the total unique descriptors within each participant group.

While the ten live participants gave the most descriptors with 214 descriptors, thirty-six workers gave a close 180 descriptors. The live participants who did the online survey gave the least amount of descriptors. Since we had different amounts of participants per group, we also did another graph, figure 4.2 that plotted the average number of unique descriptors per person in each group.

Textural Differences Between Audiences

Figure 4.3 shows the most prevalent 25 descriptors placed on a graph scaled to the log number of mentions, whether more on the Turk side on the left, or the live participants on the right. 100% difference means that the word was only mentioned in one audience. Both participants noted textural qualities like stretch, texture and woven.

Color was not only the most popular descriptor, but also significantly the most used by the Turk workers by our $\mathrm{CHI}\hat{2}$ analysis (CHI = 28.432, $p < 0.01$). Additionally, Turk workers described textural words like soft, thin and tough, significantly more than their live participants.

4.1.5 Discussion

Quantity and Cost

From figure 4.2, thirty-six workers gave close to the same amount of descriptors as the live participants holding real fabric. Our live participants may have given more descriptors due to their expertise, both in-person and online.

If finding live participants may be a challenge, Turk workers may be able to approximate on those descriptors. In terms of cost, both ended up similar. The ten live participants were paid a total of $90, while the thirty-six workers were paid $72 without Turk's fee, and including fee costing $100.80. If we had used another crowdsourcing medium with lower rates, the rates would be more comparable.

Quantity and Format of Inquiry

Live participants gave more unique descriptors holding real fabric than online task. Since the live participants gave so many descriptors, it would have been safe to assume that those same participants would be equally verbose in the online version. However, the live participants describing video gave the least amount of descriptors in figure 4.3. Averaged per person, both the live and worker participants seeing the video gave lower amount of descriptors compared to the live participants with real fabric.

The online survey design, rather than the participants, may have caused this unexpected result. As one live participant noted: *"I feel like when I was holding (the fabric), I said a lot of words. With the online version I only had 6 boxes, so I had to figure out which words conveyed what I needed. "*

While we grounded our 6 text boxes based on prior studies, it's possible that it was not enough text boxes. An alternate design would have been a giant text box, but participants may feel overwhelmed by a larger box. It's possible that a "add more descriptors" button would have yielded more descriptors, but given that we required a minimum of 3 descriptors, we are unsure how many participants in either group would add more and give more data for free. Further study needs to see the relationship between different inquiry designs and the descriptions given.

Descriptors

From figure 4.3, Turk workers significantly noted more of the fabric's color than the live participants with real fabric. Given that color is visual descriptor and that the Turk workers had to rely on fabric videos, this finding is not surprising. Similarly, the live participants significantly noted on "feel", likely as an effect of feeling the fabric directly. Live participants also significantly noted "side", revealing that the live participants more easily differentiated the fabric between one side or another side more than the Turk workers.

All participants have noticed some textural quality beyond visual qualities, such as stretch and texture. From figure 4.3, Turk workers significantly noted qualities like "thin", "tough" and "flexible". With more participants from both audiences, there is some promise that participants would share more textural qualities.

Our analysis is limited in how these participants used these words. For example, one of our Turk workers described all fabrics as soft, flexible and a color, despite the variety of fabrics shown. This is a unique case, but further analysis is needed to see whether the tangible qualities by both audiences are used in similar ways. More generally, these results reason to investigate whether Turk workers with fabric videos can approximate what live participants say with real fabric.

4.1.6 Future Work

For the next study, since the format may have influenced participants, we also want to explore different formats in inquiry for the online version before getting more participants, to be sure that our online survey format allows participants to give the most descriptors.

We want to get more live participants, and delve deeper in these questions. Our results and analyses performed are mostly limited by having just 10 live participants.

We wanted to study how fabric size affected the descriptors given, along with the ambiguity of descriptors between audiences, different formats in inquiry, and whether crowdworkers can approximate descriptors given by the live participants. With tweaks in the UI design, along with more participants, we can either see more differences between particular descriptors, or if the descriptors are similar, then the crowd may predict what real-world participants may say to open-needed tangible inquiries.

4.1.7 Conclusions

In conclusion, we sought to investigate how the crowd described open-ended responses involving tangible qualities, one that required digital mediation of fabric. Workers gave a large amount of descriptors collectively, comparable to our live participants. All participants describe the fabric not only on color, but on tangible qualities of fabric. We believe that the format of the mediated inquiry, not the audiences, influenced the descriptors given, and the current findings are encouraging to study further on the relationship between descriptors found crowdsourced or live.

4.2 Media Crowdsourcing Study

As follow-up from the prior study, we wanted to resolve the survey input issue that may have discouraged participants from inputting more descriptors and have more definitive insights to our research questions. In particular, we were interested how a participant's expertise affected how they understood the material, as a follow-up from our studies from our initial studies.

Since that study, we also had additional questions to investigate. First, we wanted to study how a participants' understanding is affected by other media in addition to video, in a controlled experiment. The prior study focused on video, but media comes in many different forms.

4.2.1 Research Questions & Hypotheses

For this second study, the research questions are the following:

1. How does the **representation of the material (images, multiple images, video, and the actual material itself)** affect a participant's understanding of materials remotely?
2. How does the **participant's expertise relevant to fabrics (0 experience, 0+ experience, crowdsourcing)** affect a participant's understanding of materials remotely?
    (a) How do descriptions from digital, non-experienced audiences (0 experience and crowdsourced) compare to experienced participants with actual fabric? Specifically, What kinds of description differences lie between experienced participants holding real fabric, and:
        i. 0 experienced participants with digital versions
        ii. Crowdsourced participants with digital versions

We want to investigate differences between the descriptors in the different media. The first studies in ambiguity did not yield differing words, yet prior work in comparing lab versus online crowdsourced descriptions for fabric has yielded different results[59]. While this is not a key research question, we are intrigued to see if there are significant differences.

An additional question we would like to observe, but not associated directly with the core research research questions, is what kinds of differences, if any, lie between the different experience levels in design and building with fabrics.

The crowdsourcing group is a more geographically diverse group than the in-person participants, but we hypothesize that the crowdsourcing group will give similar kinds of responses to the 0 experience participants. Akin to our prior studies in studying everyday participants, we do not expect many uncommon experienced participants to be in the crowdsourcing group.

A subquestion on the second research question was motivated by prediction capabilities between the different conditions. How can the crowdsourcing or non-experienced community, with digital representations, predict what experienced participants say about actual fabric? What kinds of qualities are mentioned or not mentioned, and how does that reflect on the prediction potential of non-experienced participants with the most limited of representations?

Given the substantial overlap in language between experienced and non-experienced groups in the past, we hypothesize that there is a substantial prediction potential that non-experienced groups may have. Any missing qualities that appear between representations would also appear in these comparisons as well.

4.2.2 Experimental Design

Since this study have two main conditions (expertise and media), varying across 5 diverse fabrics, we designed a within-subject study, within-subjects with respect to the fabrics and the media conditions. In particular, all participants have experienced all fabrics in random order, and have at least 1 data point per media. The first three fabrics have all media conditions shown, randomly selected, while the remaining two fabrics will be two of the three media conditions.

We hypothesize that, for the first research question, video will be the most preferred and will give the most similar kinds of descriptors than any other medium. Video simulates what participants may do with the fabric in their hands, so the video may act as a surrogate handler of fabrics.

As for the second research question, we hypothesize that there will be significantly differing language between those with some experience with fabrics, compared to those with no experience, relying on prior studies[59].

Task

The main tasks are the following:

1. Describe a swatch of fabric remotely, either as a single image, multiple images, or a video.
2. Describe the real-life swatch of fabric.
3. Compare and contrast the differences between the descriptors in step #1 and #2.
4. Repeat the prior steps for all five fabrics.

Fabrics

In the prior study, we had 22 fabrics that participants described. But, with the sizing inquiry combined with the large number of fabrics, that hardly gave us any statistical power, since we did not have enough participants describing the same fabrics.

So, after obtaining many new fabrics into the mix, we selected candidate for 5 different fabrics for this study, and consulted an expert to review the choices and present the most ideal fabrics for this study. In particular, we wanted to span different qualities of fabrics and have fabrics that have some unexpected quality to them.

Below is a list of the diverse fabrics used in this study, and some rationale as to why they were included:

1. White mesh lace fabric with sequins, unique in its opacity and sequin shine.
2. Tan upholstery fabric, particularly thick with a nap, or raised surface. The only one with a raised nap.
3. Black pleather with a unique drape uncommon for those kinds of fabrics.
4. Green lining, the thinnest from the set
5. Pink laser-cut fabric with cut out holes and diamonds, selected to be especially challenging for hobbyist and home sewers to design and imagine what to do with such a fabric

Participants

Since experience with fabrics can be measured in many different ways, we wanted first see the role of 0 experience versus 0+ experience with fabrics and how that affects how participants describe fabrics.

We have had 40 participants participate in the study, and in experience, 4 months+ experience with fabrics was a natural division between those with and without experience. The 4 months mark commonly represented someone taking a college class relevant to fabrics for a semester. This division allowed for 20 participants with 0 experience, and 0+ experience be considered as someone who has taken a minimum of a class that lasted 4 months, as opposed to a short 1-week workshop or something similar.

As for crowdsourced participants, given the large amount of diversity in that audience, we assumed that the vast majority have 0 experience with fabrics.

To find these participants for the live study, in addition to recruiting locally, we have gone to a major metropolitan areas to recruit. For the online study, we will conduct the study on Amazon Turk. For both studies, recruited through word of mouth and relevant groups through social media.

Data Collection & Analysis

Pre-questionnaires were to collect data on the *participants' experiences* in crafting, designing or building with fabrics.

The main tool was a *survey* that measured *differences and similarities between descriptors* between the remote media of the fabric and the actual fabric. We also measured *the participant's perceived similarities and differences* on the survey as well. The survey showed all fabrics once, and performed the randomization in media conditions.

We measured *user preferences* between the different media through a post-questionnaire.

The data will be analyzed similarly like in the first crowdsourcing study, employing a non-parametric CHI$\hat{2}$ test to compare different audiences and representations between one another. Data processing is similar, with some key differences, as highlighted in the section below.

Data Processing Revisited

Initially, R's textTools package was handling stemming for our various studies. That package used Porter's stemming algorithm [50]. Often, when there were errors, we had to manually convert one word to the correct stemmed term. One example was when the word to process was a color, such as "greenish". Since we were clustering colors together, normally our script would convert "greenish" to "colorish". With the Porter algorithm, the word remained as "colorish", and had to be changed manually again from "colorish" to "color".

There were other disadvantages as well to using the built-in tools to stem. The stemming algorithm missed out on different meanings that occurred with different suffixes. One noteworthy example is that "bunch" does not have the same meaning as "bunches". "Bunches" in the context of materials is synonymous to gathering, not referring to many of something. But the algorithm would detect the "-es" suffix and reduce it to "bunch", which is less informative than the gathering adjective. Also, we still needed to manually convert root words into the base word, such as converting "shini" and "shine" for ease of communicating the study findings.

Given the series of disadvantages to using the standard stemming algorithm, and after looking at alternatives, the best option remained to stem all the words manually ourselves. We checked the dataset and the processed words many times and we as moderators can be sensitive to and accommodate for words that have special meanings when describing materials, such as "bunches". We can more confidently assure that the data is stemming correctly by manually converting each word. Given the limited vocabulary that we observed in the past, the task was repetitive, but not arduous.

Procedure

Live

Each live participant filled out pre-questionnaire to collect data on their experiences. Then the participants accomplish the experiment tasks, including describing digital fabric, then the actual fabric, then reflect similarities and differences. The study concluded with a post-questionnaire. The study itelf lasted no more than 40 minutes time.

Online

The procedure for the crowdsourcing participants was the same as the live participants, except no description of real fabrics, and no comparisons made between descriptors.

4.2.3 Results

Below are results from the study, organized with respect to the relevant research questions.

User Preferences

Figure 4.4 shows an overall strong user preference of the video over all other digital representations.

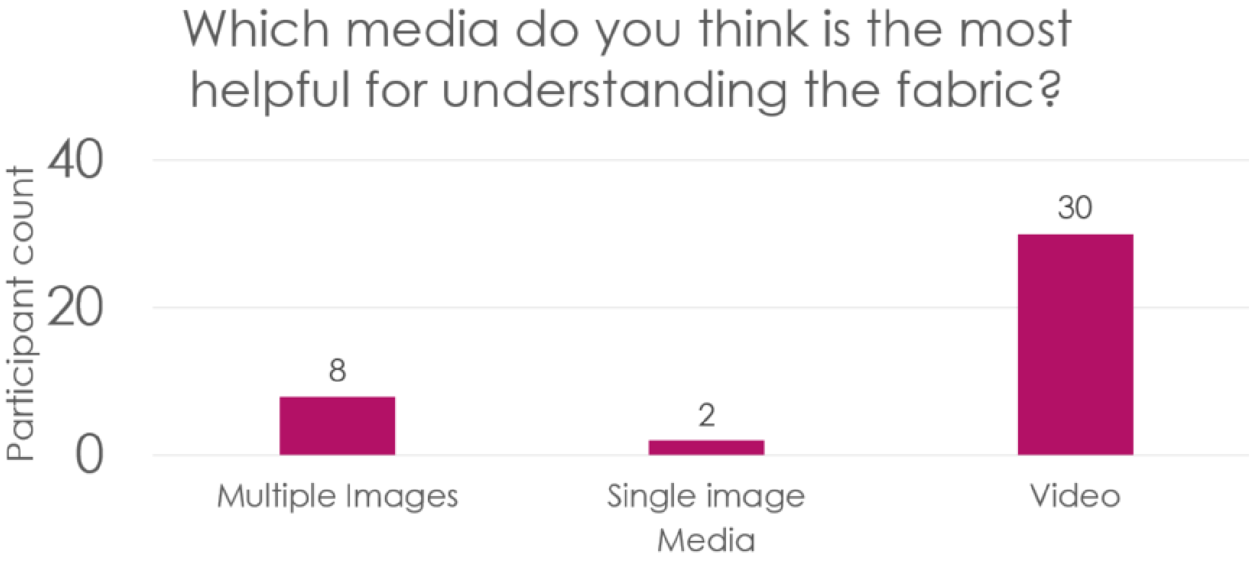


Figure 4.4: Bar graph showing participant preferences on their most useful representation. Videos were overwhelmingly the most popular result.

Influences of Expertise

Figure 4.5 compares how non-experienced and experienced participants described held fabric.

With this figure onward, the word's position indicates which audience used that word more than the other, with a word in the middle representing both audiences using the word equally. The size of the word indicates how often the word was used overall, and dark-colored words indicate words that are significantly used by one group over another, as per a CHI$\hat{2}$ test.

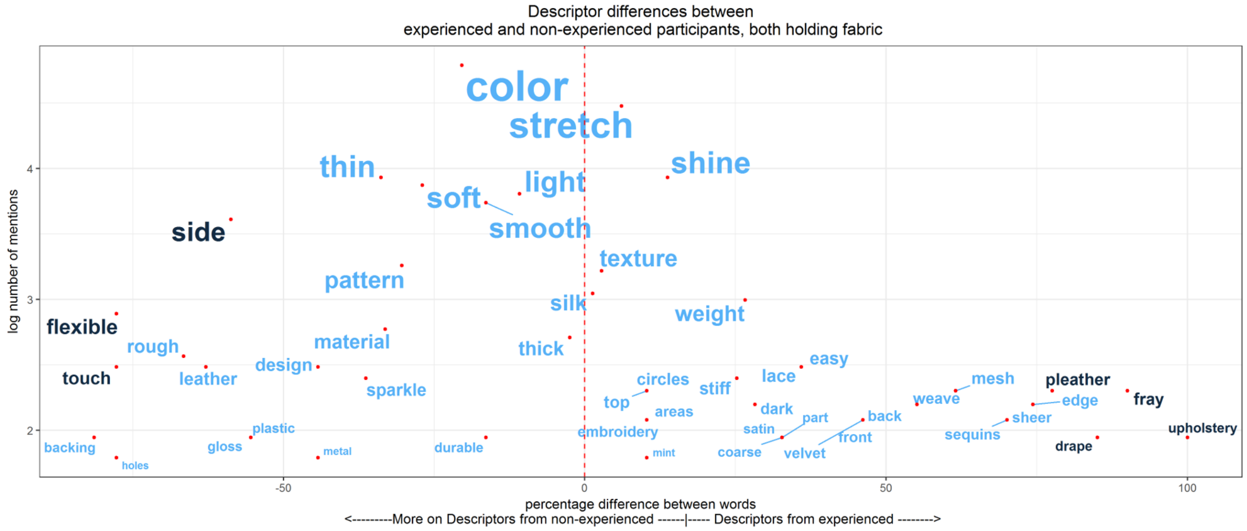


Figure 4.5: Graph of how experienced and non-experienced participants described the fabrics, with both holding real-world fabrics.

On the right-hand, or experienced side of the figure, we saw terms like “pleather” and “upholstery”, both are kinds of fabrics. We also saw the terms “fray” and “drape”, that also imply properties of fabric that experienced participants noticed, but non-experienced participants did not notice.

Both groups discussed and mentioned a variety of different properties of fabric. Properties like “stretch”, “texture”, and “smooth” were mentioned by both groups, with each of these around the middle of the graph in figure 4.5.

Influences of Expertise: Comparing Crowdsourced Participants

Figure 4.6 compares crowdsourced participants with the non-experienced participants. These comparisons with the crowdsourced participants focus on digital representations, since those are the only representations the crowdsourced participants commented on.

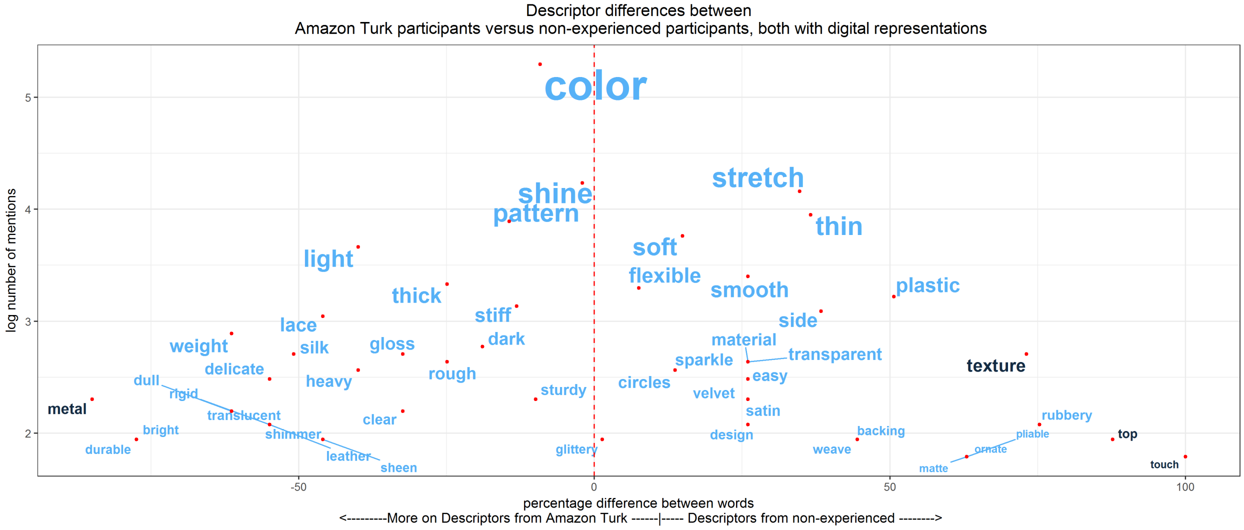


Figure 4.6: Graph comparing descriptions from the crowdsourced participants with the non-experienced participants, both with digital representations.

There are few significant differences between these two groups. The crowdsourced participants significantly mentioned “metal” more than the non-experienced participants, while the non-experienced participants mentioned “texture” more than the crowdsourced participants.

In terms of non-significant data, or what both groups mentioned, both groups mentioned color, now close to the middle. Properties like “stretch”, “smooth” and “soft” were mentioned by both, but were more used by non-experienced participants than the crowdsourced participants. Conversely, properties like “thick”, “stiff” and “weight” were mentioned more by the crowdsourcing participants than the non-experienced participants.

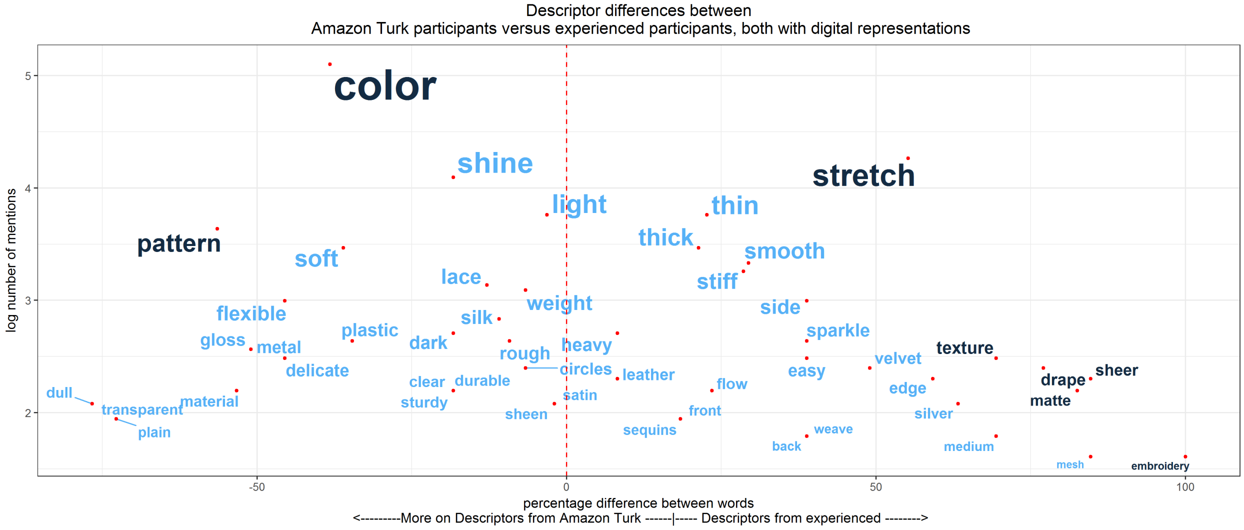


Figure 4.7: Graph comparing descriptions from the crowdsourced participants with the experienced participants, both with digital representations.

Visual properties like “color” and “pattern” were significantly mentioned more by the crowdsourced participants than the experienced participants. In contrast, fabric-specific descriptors like “stretch”, “drape”, “matte”, “sheer” and “texture” were mentioned by experienced participants significantly more than the crowdsourced participants.

In comparing figure 4.7 with experienced participants and figuure 4.6 with non-experienced participants, non-significant descriptors like “soft” and “flexible” shifted more heavily on the crowdsourced participants. “Metal” also no longer became a significant descriptor.

Differences in Representations

These figures each compare what participants said with one digital representation with what they said holding the fabric, with figure 4.8 comparing an image to fabric, figure 4.9 comparing multiple images to fabric, and figure 4.10 comparing video to fabric.

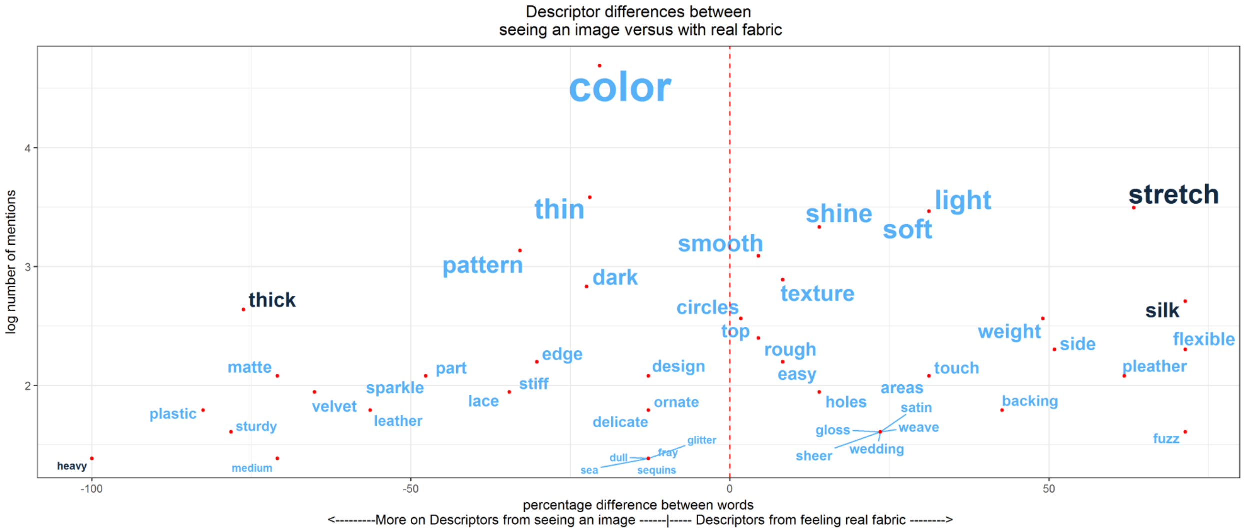


Figure 4.8: Graph of how participants described the fabrics with the image and the actual fabric.

In figure 4.8, comparing descriptors for one image versus the actual fabric, participants looking at images significantly did not mention “stretch” and “silk”, a reference to a fabric fiber content. Conversely, “thick” was not mentioned when describing the actual fabric.

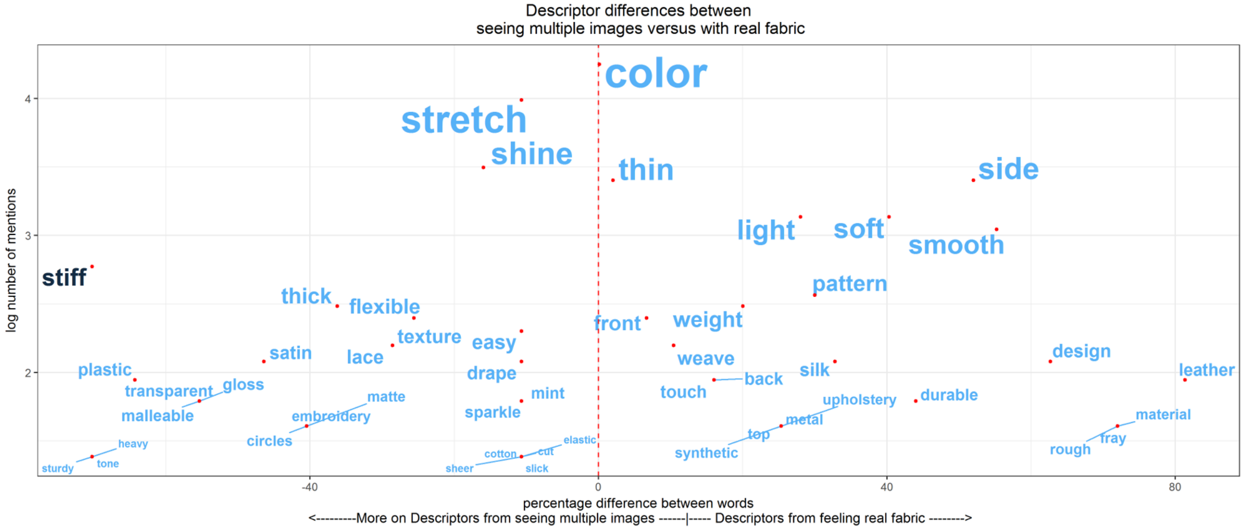


Figure 4.9: Graph of how participants described the fabrics with multiple images and the actual fabric.

Figure 4.9 does a similar comparison, with multiple images versus actual fabric. There are far fewer statistically significant results, except for “thick” mentioned when describing multiple images, but not in the actual fabric.

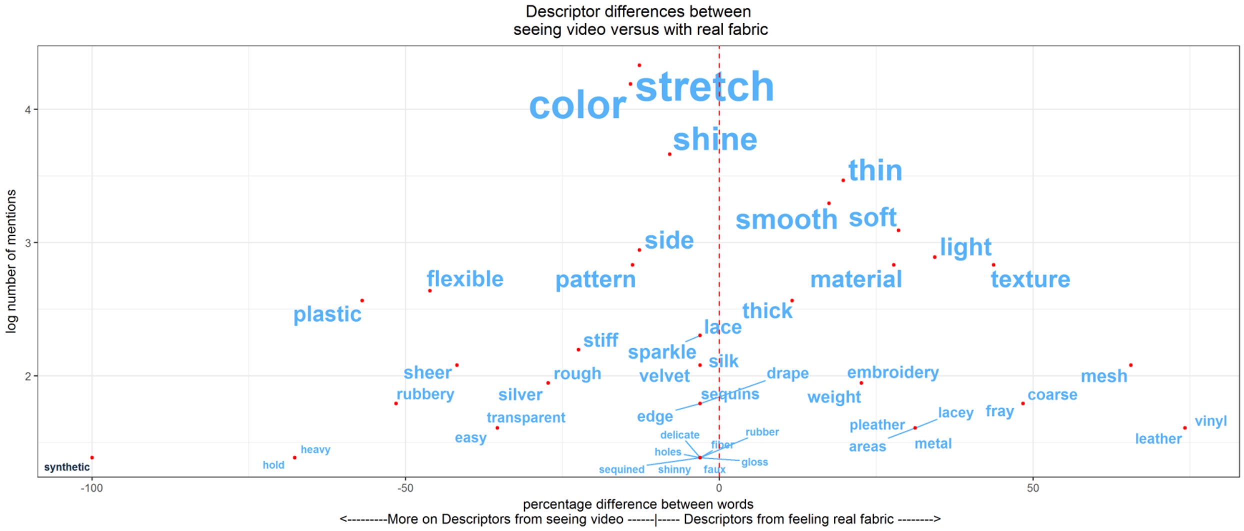


Figure 4.10: Graph of how participants described the fabrics with video and the actual fabric.

Figure 4.10, comparing video with the actual fabric, only shows one statistically significant descriptor ("synthetic") that appears when describing video, but not on the actual fabric. This descriptor was not used very frequently, however, due to the size of the word.

Similarities to Experienced Participants holding fabrics

To have see whether non-experienced or crowdsourced participants can predict what experienced participants holding fabric would describe, , we first compared these audiences, both with the same digital form (multiple images). Figure 4.11 compares non-experienced participants with experienced participants holding fabric, while figure 4.12 compares crowdsourced participants with experienced participants holding fabric.

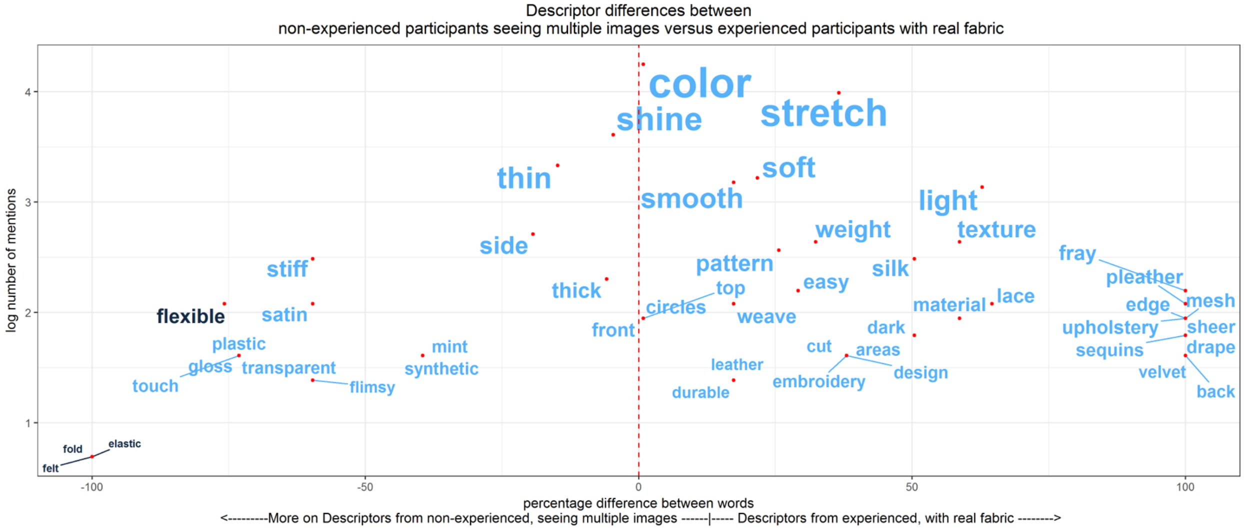


Figure 4.11: Graph of how descriptors from non-experienced participants with multiple images, compared to experienced participants holding real fabric.

In figure 4.11, the only statistically significant difference between the non-experienced group seeing multiple images and experienced group seeing fabric is the “flexible” descriptor. While not significant, the distribution of words is skewed, with more words said by experienced participants with fabric, rather than non-experienced participants with digital versions.

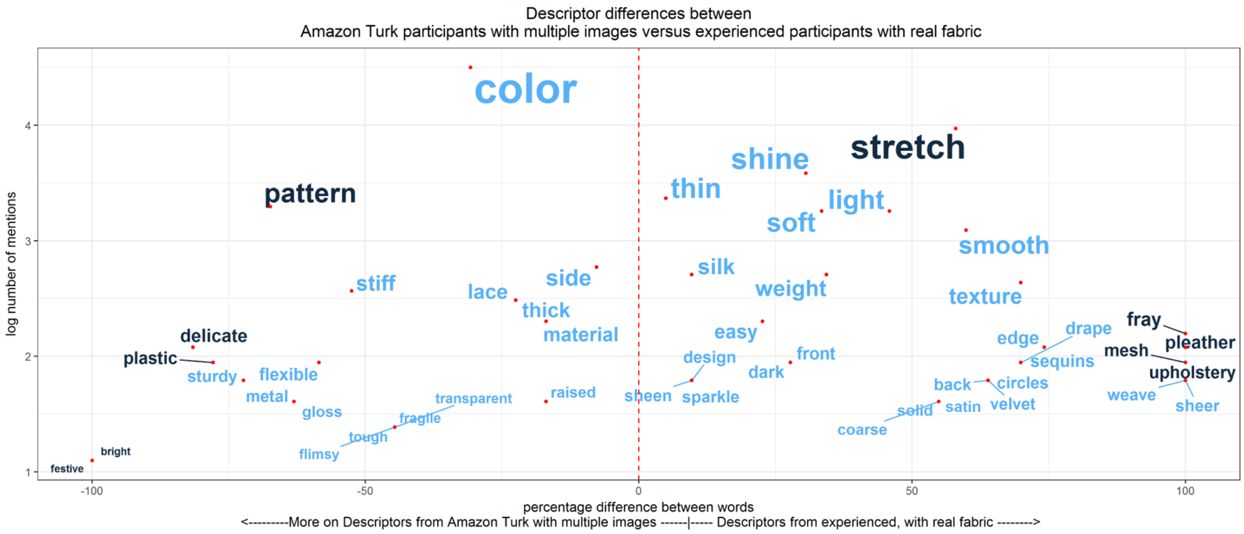


Figure 4.12: Graph of how crowdsourced participants described the fabrics with multiple images and the actual fabric.

In contrast, as shown in figure 4.12, there were far more significant differences between the crowdsourced group and the experienced group. A familiar significant cluster of “pleather” and “upholstery” were mentioned by experts, along with “fray” and “mesh”. “Stretch” was also missed by the crowdsourced group and mentioned by the experienced group. Far more fabric specific terms and properties became statistically significant than the prior figure comparing the non-experienced participants.

The “pattern” description was the only visual property that was significantly used by the crowdsourced participants over the experienced participants. Visual properties like “Color” were not significantly used by one group over another.

4.2.4 Discussion

In terms of the media question, video helped participants give the most similar information to holding the actual fabric in their hands. Video was also the most preferred representation.

Multiple images still did not have many significant differences between descriptors. The most significant differences was that fabrics may appear to have some quality relevant to stiffness in the multiple images, that was not used when holding the actual fabric. Images had the most descriptors with significant differences, with thickness becoming the most prevalent.

In terms of expertise, specific experienced-specific terms did exist, but there were few present, and even those terms had similarities to what non-experienced would use. An example was the experienced participant’s usage of words like “pleather”, when a non-experienced participant may have used “plasticy” or “synthetic”. Both “plasticy” and “synthetic” may be considered synonyms, but neither were statistically significant.

Insight from Non-Significant Data

While we could not extract directly design implications from non-significant information, we saw crucial trends in different ways. The first way was observing what groups of varying expertise discussed with a similar frequency, or descriptors in the middle of the graph.

Also, for descriptors that were mentioned by one group over another, we saw trends in some descriptors. For example, the crowdsourced participants mentioned visual properties like "color" more than others, in this in the prior study. In particular, "color" was statistically significant in the first crowdsourcing study. But in this study, as we had more participants and controlled for expertise, color was only significant with large differences in expertise.

Other fabric-specific descriptors like 'texture" varied and shifted in the graphs, without any strong sense of being influenced by expertise or representation. One interpretation may be that more participants may find more differences like with "color". But since this work studies how expertise and representation affect understanding, the non-significant data shows similarities. Indeed, we saw many similarities in understanding from different audiences and representations. After all, one of the core contributions of this work is the potential for crowdsourcing to make sense of materials in similar or different ways than experts, and similarities influence our recommendations.

Crowdsourcing Description for Materials

Descriptors from crowdsourced digital representations were more diverse than the non and experienced groups. This difference may be attributed that both the non-experienced and experience participants both held actual fabric, and picked up on different descriptors throughout the study.

We hypothesized that the non-experienced participants are similar to the crowdsourcing community, and while there were little differences between them, the differences were far more prevalent between the crowdsourced and the experienced participants in whatever representation. The digital versions contributed to helped separate these two groups. These differences became more prevalent when checking for predictive power of the crowdsourced participants against experienced participants holding real fabric.

While this comparison gave the widest differences, the significant differences still were 8 descriptors. For the crowdsourced-experienced digital comparison, visual qualities like color were mentioned by the crowdsourced community more, similar to the prior study.

4.3 Understanding Expertise Study

From the last study, we found few differences between how experienced and non-experienced participants described fabrics. But, we were looking at the core individual words. We wondered if there are other cues that differentiated between experienced and non-experienced participants.

Such differences, if found, would have profound implications in how to design interfaces to represent these materials, including what these different users value, and how they perceived materials remotely.

4.3.1 Research Questions & Hypotheses

This study focuses on a few hypothesized differences, collected from the prior studies, and evaluating them using the dataset from the prior study.

Below are our research questions, along with our rationale:

1. Are there significantly different ways in how experienced and non-experienced users interpret and describe fabric, with respect to the following two characteristics:
    (a) **Future tense use**: We hypothesized that experienced participants saw fabrics as what they could be, or what would they use the material for, in a future tense, and that this future tense usage would be significantly used more than non-experienced participants. The future tense use was one we saw in earlier studies, with the first one in section 3.1, where one designer posited that they *would* use a fabric as a prom dress.
    (b) **Applying a context**: Our second hypothesis is that experienced participants would see the fabric in a specific context more than non-experienced participants. We would capture how a designer sees that fabric being applied, or if that fabric reminds them of something specific.

Our rationale for looking at future tense and context stemmed that designers describe fabric through application and in terms of what that material could be, while non-experienced participants directly describe the material.

To clarify what we were looking for in each of these characteristics, if a participant said that they "would use (a fabric) for a prom dress", the "would" word would represent a **future tense**, while the "prom dress" would be be **applying a context** to the fabric.

4.3.2 Experimental Design

This study is purely an analysis on the dataset collected in the prior study. Specifically, focused on the live experienced and non-experienced participants' answers to digital and real fabrics. We chose this portion of the dataset, since the crowdsourced participants were more diverse in responses than the non-experienced participants, and the live participants, experienced or not, have had ten instances to described fabric(5 descriptions of fabric digitally, and 5 of describing those same fabrics live).

The procedure of analysis was to organize the dataset and have each participant's expertise and what they said to all fabrics. We performed data processing on that dataset, tracked whether the response used one of the qualities we were looking for (future tense use, or had a specific context in mind), and counted how many times did those characteristics appear in the dataset. The below section described in more detail the processing and analysis involved.

Data Processing & Analysis

Our dataset was composed of the participant number, whether they have 0+ experience or not, and their response for the digital and the real version of each fabric. Each response, digital and real, was marked as using the future tense and/or bringing in a context.

The labeling we used is per fabric and not per participant response, because each fabric is a potential reaction for the participant to describe it with a particular quality. Since any one participant may use the same terms in describing the digital and real version, both the digital and real version of the fabric was combined as one data point. For example, if one participant used the word "rug" in both the digital and real version of one fabric, our processing counted one instance of using context. All participants described 5 fabrics, so any participant have the quality, at most, 5 times.

To mark the future tense usage, had a list of future tense verbs in the English language, along with checking the actual dataset, and marked whether a response used the future tense or not.

To mark contextual usage, since cue is at the phrase level, manual combing of the dataset was required, reading every single item and tagging the appropriate words that indicated context. Since context can vary wildly between participants, collecting relevant keywords was needed, and checking that such words really were used to describe a specific context.

To focus on context, we excluded any references to other kinds of fabrics in our tagging. If a participant described a fabric "cottony", the participant may be thinking of a specific context to use the fabric. But more likely, the participant was trying to identify the fabric specifically, rather than thinking of a specific context. Additionally, "plasticy" would likely be describing the fabric itself and not a specific context. But objects like a "plastic bag" would be reminiscent of a specific context.

4.3.3 Results

Figure 4.13 and figure 4.14 show how many times have participants described fabrics with the future verb tense and with a specific context, respectively.

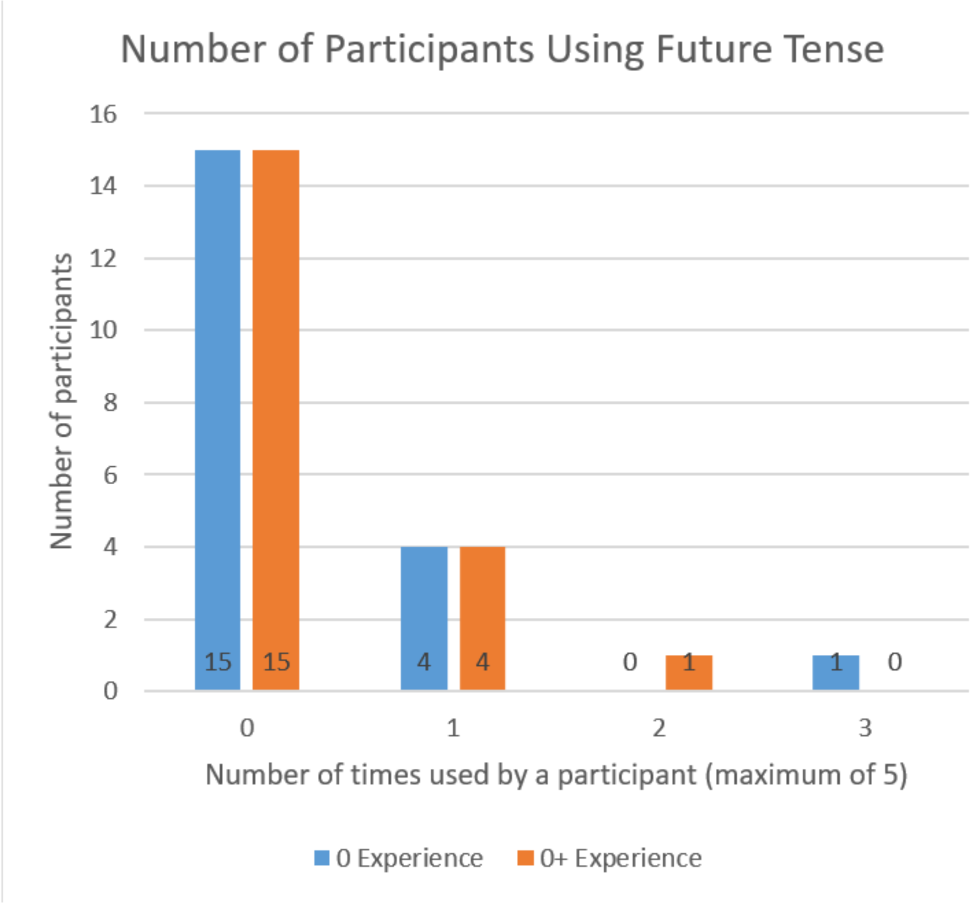


Figure 4.13: Graph illustrating how many times did participants mention a future tense to describe a fabric, from 0 to a maximum of to fabrics. Like in the prior study, participants were classified as having 0 experience with fabric, or 0+ experience with fabric. No one used the future tense to describe 4 out of the 5, or all 5 fabrics, so those entries were omitted in this graph.

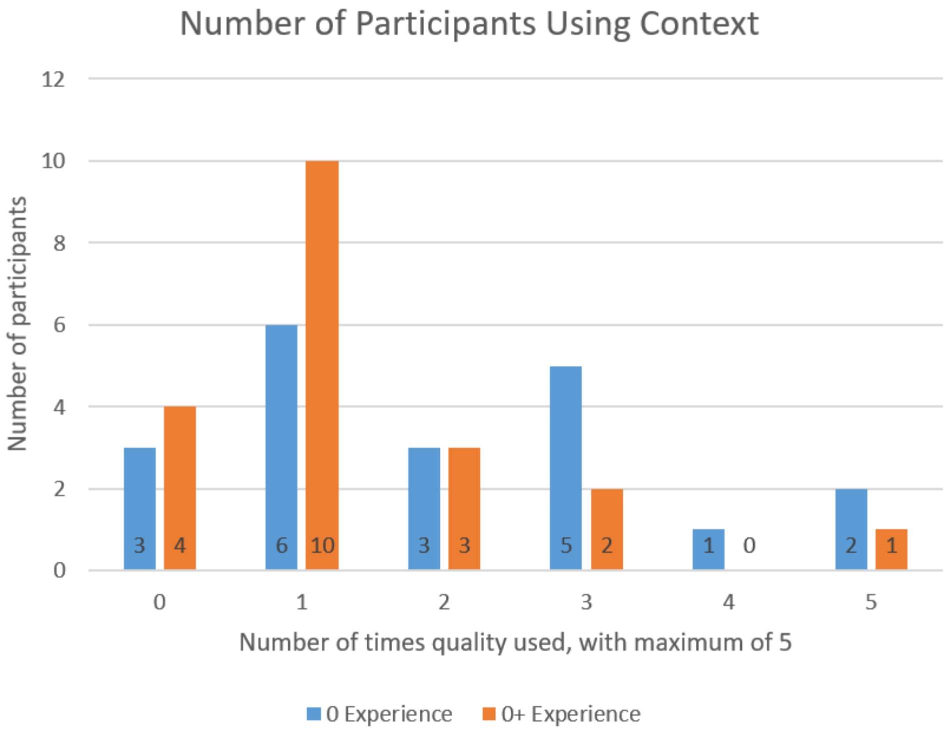


Figure 4.14: Graph illustrating how many times did participants illustrate or mention a specific context when describing fabric, between 0 to a maximum of 5 fabrics. Like in the prior study, participants were classified as having 0 experience with fabric, or 0+ experience with fabric.

Both groups of participants, 0 experience and 0+ experience, had similar kinds of frequencies in mentioning either future tense or context. The vast majority of participants did not use future verb tense. Only 5 out of 20 participants in each group used future tense, and both followed similar quantities.

In terms of applying a context, we see similar trends as well, but with a higher quantity. There are two differences in figure 4.14. Four more experienced participants mentioned context once more than the non-experienced participants. Also three more non-experienced participants used context three times, more than experienced participants. Given that these numbers are out of 20 participants per group, these differences overall are likely to not be statistically significant.

4.3.4 Discussion

We see potential for further investigation, since we did not find any clear differences in how experienced and non-experienced participants describe fabrics. More investigation is needed into more cues that could separate and distinguish the role of expertise in description. The future verb tense analysis was done with individual future verb tenses, but the contextual cue analysis was done on the phrase level. It's possible that further work needs study at the phrase level and see if there are differences between these two audiences, and how they interpret materials remotely.

Additionally, if the experienced participant did not see any use for this fabric, they will not any idea nor desire to work with the fabric. The five fabrics selected were diverse but did not necessarily span the breadth of variety of different fabrics. If an experienced participant worked with a specific aesthetic or set of design constraints, such as solely working with quilting cottons or focusing on weight and texture exclusively, unless specific fabrics are being described, that application may not present itself.

Additionally, our prior study looked at experience, but there are a variety of different experiences that would shape how the participant would interpret the fabric. How do designers, builders, hobbyists and the casual stitcher interpret materials, and are there differences between them? While more participants may lead to statistical significance, it is also important to consider how practitioners approach their materials.

4.4 Implications for Design

4.4.1 Digital Representations

Participants preferred video as their most useful media, while we found the few significant differences between descriptors from seeing video, compared to actual fabrics. These results may be attributed to the video performing gestures on fabrics that the participant may have done themselves with the actual fabric.

While video was successful as a media to communicate materials, multiple images provided many similar terms. So for practical purposes, if other factors deter designers from showing video, such as bandwidth, lack of video equipment, or other constraints, multiple images served as a good substitute.

4.4.2 Materials in general

For materials in general, the video finding more broadly implies to consider what users normally would do when encountering the material, and have those designs reflect those interactions. The gestures from the video were inspired by properties of fabrics and gestures that designers would do when exploring fabric, so the gestures for a particular material may differ.

Similarly, it is also important to design your representation to capture subtle differences that are not very apparent. One of the more prevalent differences between digital forms and the actual fabric was thickness. In the case of fabrics, thickness was one of the properties the most difficult to deduce from any remote media. In part, fabrics are relatively thin compared to one another, and compared to other materials. So this came up as a difficult property to represent among all the other fabrics.

For materials in general, this subtle property can change depending on what materials to observe. For example, in propwork, weight may be a challenging property to represent, since it's based on feel and how strong the holder is.

At the word level, we did not find many significant differences between experienced and non-experienced participants and the crowd. These findings also imply that the crowds and experienced participants do have some overlap; though, given that there were more significant differences between the crowd and experienced participants compared to non-experienced participants and experienced participants, it was incorrect to assume that non-experienced participants were similar to crowdsourced participants. It's still unclear what specifically those differences are, and how that affects the crowdsourced participants' potential to predict how experienced participants describe materials.

4.4.3 The Role of Crowdsourcing in Describing Materiality

Like reinforced in the prior two crowdsourcing studies, the crowdsourcing community picked up visual qualities far more than other participants. There were several fabric qualities not deduced by the crowdsourcing community, but practitioners looking to employ crowdsourcing for materiality would find reasonable success.

It is recommended though to supplement the descriptors with participants holding the actual fabric, ideally with experienced participants. Though, not nearly as many experienced participants are needed compared to crowdsourcing, since our comparisons compared 40 crowdsourced participants and 20 in-person participants.

4.4.4 Revisiting Ambiguity

Since the video representation had the most similarities to the actual fabrics compared to the other representations, it's likely that the video representation gives the least room for interpretation, and narrows the ambiguity more than the other representations. Conversely, the image left the most room for interpretation, was the least clear, and opened up more room for ambiguity on that material.

Specifically, the kinds of ambiguities that persisted were related to properties that are similar to all fabrics (thickness, stiffness, etc). In this study, those kinds of properties left the most room for ambiguity, though could be rectified with further iterations on the video design.

Regardless of the representation, word-level ambiguity still persisted, so any word was subject to multiple interpretations.

Word versus Phrase-level Analysis

At the word level, there were very little differences between experienced participants and non-experienced participants; but the phrase level holds some potential for getting the essence of the description, going from “stretchy” to “stretches on the bias and has a bit of stretch on the warp”, for example. Even a smaller jump, from the word to the adjacent-word level may yield a decent idea of the description, from “middle” and “weight” to “mid-weight”.

The adjacent-word and phrase level, however, encouraged ambiguity, since there are more words to interpret, and would give us researchers a harder opportunity to see similarities and differences in description.

At the individual word unit, the ambiguity interpretation is narrowed, but we still learned about select differences that appear in describing different representations and with different groups. We also were able find more similarities between participants with the individual word processing, so “stretchy” and “stretches on the bias” both count for the same word. That individual word was used in different ways, but that also gave us the opportunity to see how different words were interpreted as well. Accessing ambiguity at th word level gave us access to the diversity of ambiguity at the phrase level, a guideline we carried into the systems design in the next chapter.

Inquiry of Description

We asked our participants to describe fabrics, enabling participants to describe whatever salient properties came to mind. If we wanted to narrow the ambiguity and be more clear with our inquiry, we could have asked pointed or more guided questions with respect to defined and mechanical properties of the fabric, like asking to describe the surface feel or density of the fabric. Or, more broadly, our inquiry could have asked their opinion on general properties, and gave the participants ways to interpret those properties, like asking participants to describe the color and texture as two separate questions.

Our inquiry on description was the most broad that allowed for the most ambiguity. That is, “soft” could have been used to answer a texture-related or a color-related question, but we chose to keep the inquiry broad for supporting multiple interpretations. Another advantage with this kind of inquiry is that our inquiry did not make prescription on how to interpret the fabric; it allowed the participant to make their own interpretation on how they used “soft”, without implying that it should be used to describe “texture” or “color”, among others.

An alternative way to inquire would be to ask participants what would they use the fabric for, or what they would kinds of things would they make with the fabric. The disadvantage with this inquiry is that it biases towards those with experience, who could speak more to the application of materials, rather than the non-experienced participant.

In practice, it's challenging to bridge the gap between description and experience. But again, like fingers pointing to the moon, description only points to the experience [43].

4.5 Conclusions and Future Work

In these series of studies, we explored how expertise, media form and crowdsourcing affect a participant's understanding and interpretation of a material remotely. We have found specific qualities that were difficult to communicate in the digital representations compared to the actual materials at hand. We also found that digital representations that imitated what users would do interacting with the material were the most successful in communicating as much of the material as holding the actual fabric.

Future work involves more deeply studying differences between experienced participants, non-experienced participants and crowdsourced participants. Our findings may have found limitations in what could be inquired by the crowd, but we are still not sure why these differences have appeared.

Chapter 5

Exploring Materials in the Field

Between these studies, we also recorded anecdotes relevant to fabric, including their process in exploring and finding a desired fabric. While these findings are not from directly measured results from studies, we have recorded how participants chose fabrics.

Our participants have given different kinds of practices, that can be summarized briefly in the list in the sidebar section 5. These practices ways in how they communicate, refine and change their ideas, independent of their starting point in the design process. These practices applied whether a participant may begin with a precise, high-fidelity idea of a specific fabric, or with a low-fidelity general idea.

1. **Use fabric** swatches, or small samples of fabric, from repositories or collections of fabric, to explore or find a desired fabric.
2. **Use descriptors**, specific fabric references, locations in store (fashion fabric, lining, drapery, upholstery sections), and other words to explore fabrics that match those ideas.
3. **Iterate** using practices from #1 and #2, until an ideal fabric of desired quantity is found.

5.1 Fabrics-Focused Approach

The first practice revolves around physical fabrics. The fabric bin concept was a pre-existing repository by costume designers, added as new fabrics came into the costume shop. The practice of collecting fabric swatches is also common among those that create handcrafts [56]. Similarly, the providing physical fabric swatches is commonplace in fabric stores, in-person or online.

5.2 Qualities-Focused Approach

The second practice observed is to use various descriptors and ideas to help communicate ideas of some fabric. Some described fabric by identifying the exact weave and composition of fabric, or general descriptors like “thick” or “heavy”, or contextual words such as “feminine” or “rich”. One seasoned fashion designer described fabric relative to an audience in mind that has a set of fabrics associated with it. An example would be “denim for toddlerwear”.

5.2.1 Fabric Swatch Search

One real-world example of a quality-focused approach was situated when a designer did not find what they were looking for locally, and either did not want to shop online, did not find suitable fabrics online, or in other words, the online fabric experience did not serve them.

The designer may then ask a colleague in New York, Los Angeles, or in a major metropolitan city with a fashion district, to help find what they’re looking for. In order for the colleague to get a sense of what to find, they have a conversation focused on what qualities to look for, or to avoid. Below is a short example of what the dialogue may look like:

Designer A: *“I’m looking for something that has a nice flow, a period fabric.”*

Designer B: *“What if it’s a velvet?”*

Designer A: *“If it’s a lightweight, silky velvet, it can work. But it has to be lightweight”*

In that dialogue, the designer B better understands what qualities the designer was looking for(period, nice flow, lightweight), avoiding, options(can be a velvet, silky) and what qualities may not matter (no mention of qualities like shine).

We applied Paul Grice’s Maxims in conversation to interpret conversations reaching a ground truth and interpreting ambiguity [24], to get a better sense of the dialogue. They highlight four maxims (Quantity, Quality, Relation, Manner) to interpret conversations.

Specifically, B could have read A to be informative, following Quantity, and that velvet would meet that criteria. Designer B reads velvet as a fabric that has nice flow and reads like a period fabric. Alternatively. Designer B asks this of A, and A clarified that that a subset of velvets would match A’s vision of what A’s looking for. In following with Relation, to A, “nice flow” and “lightweight” have some connection to one another.

While quality may guide that the subset of velvets that is lightweight may be the only fabric that meet’s A’s criteria, it’s possible that many other fabrics may meet the criteria. A views “lightweight” as an important quality.

5.3 Combined Fabric-Qualities Approach

Participants reported iterating using a combination of the two strategies to help explore fabrics. One participant, a seasoned hobbyist seamstress, anecdotally shared that she found a knitting pattern that recommended a specific yarn. She did not want to use the recommended yarn, but wanted something similar and particularly soft. So she went to a yarn store in-person, and began exploring yarns by feeling them, using the given one as a starting point, and branching out to soft ones. After picking one, and finding that the in-person store did not have enough in stock, she simply recorded the product number details and purchased the desired yarn online, with the confidence of knowing exactly what she was purchasing. While yarns are not fabrics, yarn is a similarly tangible domain that shows both using “soft” descriptors and specific materials in mind.

5.3.1 Exploring in a Fabric Store

Another example of this fabric-quality iterative approach was from one anecdote shared by a quilt shop owner. When asked if there was ever a situation where it was a challenge to help a customer find what they were looking for, one quilt owner that it happened very often and shared her process.

The owner asks the customer what appeals to them, and they may share that they want something in “blues”, as an example. The owner then finds fabric in blue with a variety of qualities, like florals, geometrics, tone-on-tone fabrics, all in blue. Since quilting usually requires fabrics of many kinds, the owner would provide anywhere from 8 - 20+ fabrics.

Then the owner invites the customer to pick out what catches their eye. If the customer picked a blue fabric with a geometric pattern, then the owner fetches other similar kinds of geometric blue fabrics. The owner may pull anywhere from 15-20 fabrics at this stage. The owner also includes some oddballs varying in some other quality, because quilts also often need a different color for their desired color to pop-up.

The process of pulling fabrics, deducing a desired quality, and finding similar fabrics that met that quality, is a process that relies on the fabrics and the qualities together.

Chapter 6

Fabric Web Application

Relying on prior work, we developed a system that helped us understand how designers explore fabric remotely and how they negotiate and make sense of the ambiguity in information.

The *System Design* section discusses designs for navigating and exploring fabrics, including how fabric and ambiguity are represented in the system. In *Development*, we discuss implementation details and the evolution of the system. *Final System Walkthrough* shows the final result of the design and development.

6.1 System Design

We are using these word associations in our design for an application that helps designers find and explore virtual fabric both by moving virtual fabric and performing textural searches, so that our application can suggest fabrics and similar words to the designer.

Designers that use our system may have little idea of what kind of fabric they are searching for, and may prefer exploring the selection of fabric available, to help narrow their designs. Others may have a clear set of descriptors of the kind of fabric desired.

To support these potentially different ways to browse and search for a desired fabric, we investigate different representations and different designs to understand how designers understand fabric.

The section begins with our design goals for this system. Then, in the *Interface Designs* section, we discuss views for how to interact with and explore fabrics holistically. We present interface designs that support exploration and how designs work together, and for each one, we show how the design has changed or evolved. One of the designs shows how fabric was represented in the system, highlighted in the *Representations of fabric* section. We also have a initial design *storyboard* of how we imagined these interactions happen together.

6.1.1 Design Goals

We have two design goals:

- Show a variety of different **representations of fabric** without feeling fabric directly. We want to use existing technology and the ambiguities in descriptors to represent fabric in different ways. To leverage the tangible nature of fabric, we want to represent the fabric in an interactive way. We also wanted to explore virtual fabric and different ways to interact with it.
- **Design with ambiguity as a resource.** We want to take advantage of and preserve the ambiguities in the dataset, since no one person should dictate what is the "true" or "correct" descriptor for the fabric. We do not want to delete or eliminate potentially important descriptors.

6.1.2 Interface Designs

We designed interfaces that incorporated the existing practices that participants reported. To limit the discussion at a high level, we chose not to discuss in depth on the individual representations of fabric, and just show images of fabric.

Fabric Bin

Figure 6.1a shows our fabric bin interface, starting with exploring fabrics first, akin to the first fabrics. The screen starts with a list of all fabrics available in a pile, and like in a real fabric bin, the user browses and explores the pile.

In keeping with the practice of having many scraps of fabric in one place, this design shows all fabrics at the same time.

Swatches Box

The pink box in 6.1represents an empty box where users can put fabrics of interest. Leveraging how designers took and set aside different swatches of fabric, we allotted a separate area where fabric of interest may be placed. A browsing mode, inspired by the fabric bins in our first study, has all the fabric on display.

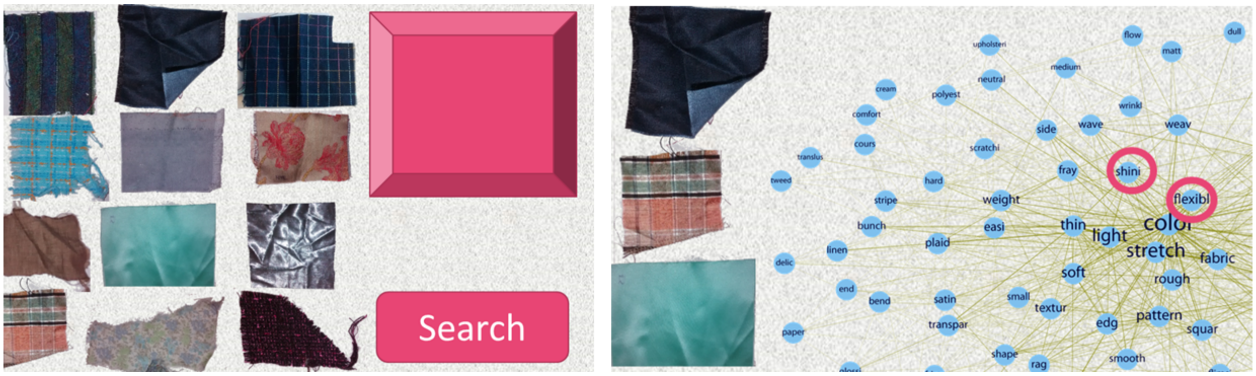


Figure 6.1: **(a)** An early design of a fabric bin interface, where all provided fabrics are shown to the user. On the upper right hand of the screen is a separate box for the user to keep compelling fabrics from the rest of the set. A search box is provided on the lower right hand side of the screen for participants to do a text search. **(b)** An early design of a semantic-driven interface that starts with a collection of descriptors. As the participant selects descriptors, relevant fabrics appear on the left-hand side of the screen. The participant can select multiple descriptors, such as “flexible” and “shiny” to explore fabric.

In the initial designs, we envisions that all fabrics may be seen at a glance in the box using an organization metaphor like tabs or stacking. But, since it’s beneficial for designers to see all the fabrics at once, like in the fabric bin design, we found it equally useful to devote a separate view for swatches only.

Search

Figure 6.1b shows our initial designs for a semantic network interface, championing descriptors like in the second practice. The screen provides descriptors in a network, each node with a descriptor, and similar nodes are connected by a thicker line.

Any individual descriptor is selectable, and if a participant selects a descriptor, relevant fabrics that have been labeled with that descriptor, are shown on the right hand side. Multiple descriptors can be selected to narrow the fabrics pile.

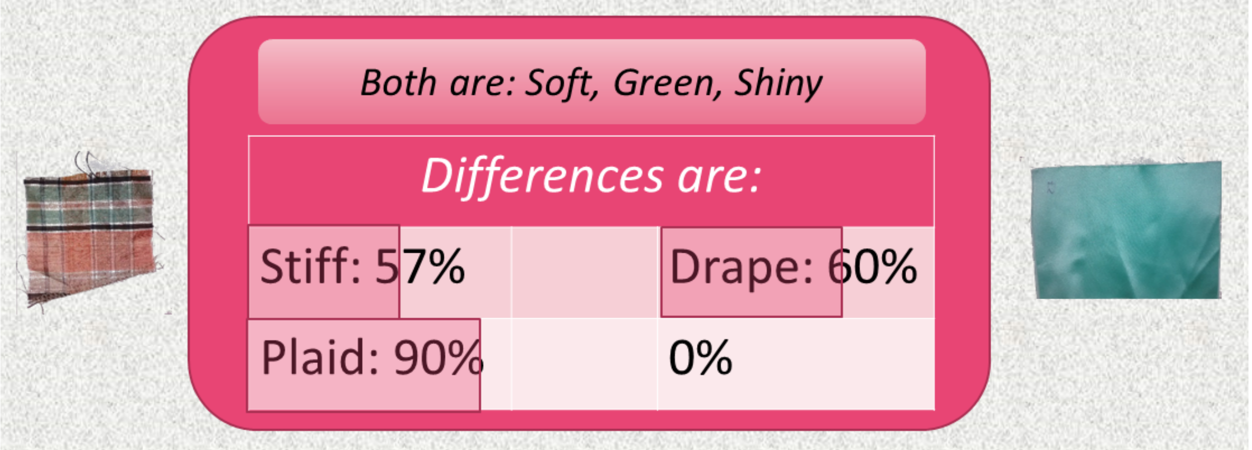
As this design evolved, the semantic network showed to be too overwhelming, and changed to a drop-down list interface, where users would select a quality from a drop-down list. We made this change because the swatches dialogue practice emphasized that qualities needed to be both included and excluded. we decided to shift the design from interacting with a semantic network to a search interface. We felt that users could get access to all the qualities and have users type in those words in a search interface rather than a drag-and-drop interfaces with the nodes in the semantic network.

In this search interface, as a user types in their query, the interface shows a drop-down box of words matching the query as they type. With this approach, users would still get access to all the available descriptors.

Differential/Compare Interface

Figure 6.2 shows our differential, or compare interface, one that incorporates the first two practices. Prior to this screenshot, the participant has selected two fabrics to compare. The screenshot highlights how to highlight similarities and differences between the fabrics. Like the prior interface, any descriptor is selectable to show fabrics relevant to the descriptor. Similarities and differences are highlighted, along with qualities that are comparable or and qualities that are unique to a fabric, like the "plaid" in the figure.

For example, in figure 6.2, 60% of participants who described the rightmost fabric used some drape term, while stiff, a close opposite, described the leftmost fabric with 57% of participants.



Both are: Soft, Green, Shiny

Differences are:

Stiff: 57%		Drape: 60%
Plaid: 90%		0%

Figure 6.2: Design of our differential interface. The interface starts with fabric, and wanting to compare two fabrics. The screenshot shows descriptors that are in common with the two words, along with differences between them, and how prevalent are the differences in each fabric.

Figure 6.3: Using the differential interface, if a user wants a fabric that is in between the stiffness of the two fabrics, the user can click on the darker area between these descriptors, and see a fabric swatch that is an intermediary.

If the user wants a fabric that is in between these two fabrics in terms of stiffness, the participant can click on the space between "stiff" and "drape" and show a new list of fabrics, as shown in figure 6.3. After exploring more fabrics that are of a desired stiffness, the process begins again, whether by clicking on individual fabrics, exploring descriptors, or finding fabrics that are in-between two fabrics, reflecting on the iterative nature of exploring fabric.

6.1.3 Representations of fabric

We have identified various ways to represent fabric, both from literature, from various prior practices, and from our observations in prior studies.

Our designs show all representations on the same page, so that the user has all the information at a glance to make sense of the fabric.

1. **Graph**

   This representation puts an image of the fabric in a one or two axes graph, with an axis representing a property or descriptor. The graph representation is one used in Industrial design to compare different materials to one another[4], which also is a viable representation.

   The initial designs had fabrics plotted on a 2D graph, based on two qualities of the fabric. This visualization was one of the ways to compare fabrics. But that specific 2D graph design was no longer used, since designers may be interested in more than two qualities.

   The graph representation evolved from a 2D graph of fabrics, to a co-occurrence graph of all the words used to describe one fabric. The data source for this representation comes from descriptors said by people throughout the prior studies, giving us a rich set of descriptors and ambiguity. This form of a graph gave designers ideas for different ways to describe or think about the fabric.

2. **Image/s**

   This representation is a common way to show fabrics. We reused the images from the prior crowdsourcing studies, showing a snapshot of the fabric draped, gathered stretched and moved, along with seeing the fabric's front and back sides.

   From iterating with prototypes, we found a need for a zoomed-in, up-close view of the fabric, to get a sense of any naps in the fabric, the thread thickness and count, among other properties. Since that kind of information was difficult to see in other representations, shy of anyone mentioning these qualities explicitly, we chose to reshoot fabrics in a close-up view to be used in this study.

3. **Video**

   This representation is a video of a fabric, a visual-temporal representation. Similar to the videos for the crowdsourcing studies, the video shows a fabric swatch being draped on hands, waved, stretched, held, and placed under different lighting conditions. Physical fabric normally undergoes several manipulations including gathering, stretching and twisting[51], and our gestures will span those manipulations. The gestures are under suggestion and recommendation by a design expert. Each fabric would have a video where the same actions are performing on it, with the same lighting conditions.

4. **Virtual Fabric: Keyboard and mouse**

   Using a commodity keyboard and mouse as input, this representation allows the user to interact with a virtual modeled fabric. The virtual fabric is modeled off of real-world fabric, and in our current prototypes, the user controls a ball as it collides with virtual fabric.

5. **Virtual Fabric: Hands**

   Using modeled, virtual fabric, this condition allows the user to interact with virtual fabric directly with their own hands, similarly to how designers interacted in our first study.

Below is a table summarizing the different representations. The key characteristics summarized are interaction, the kind of representation, and on real versus modeled fabric.

Interactions with virtual fabric in the same way as real-world fabric, such as lifting and draping the fabric over one's hands, leverages a designer's existing behaviors with fabric.

Interacting with one's hands is much closer in behavior to what designers do with real fabric than the keyboard and mouse scenario. The key disadvantage of these approaches is interacting with virtual or modeled fabric, where the quality is left up to a combination of the core systems' capabilities and a modeler.

In contrast, a video of the actual fabric *without* interaction is the closest in representing the real-world fabric compared to all other representations. Yet, it lacks in interactivity.

Interaction, modeling of the fabric, and the static or dynamic representation, all may be important for a designer to understand the fabric. So, these conditions have enough variety between these variables to help guide us on how each are useful for the designer.

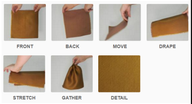
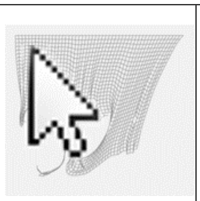
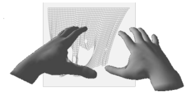
Representation with qualities	 Graph	 Images/s	Video	 Keyboard and Mouse	 Hands
Type of representation	Static, graphical	static	static, temporal representation of real fabric	dynamic, of virtual fabric	dynamic of virtual fabric
Interactive	No	No	No	Yes, controlling an object to collide	Yes, with hands
Real or virtual, modeled fabric	Real	Real	Real	Virtual	Virtual

Table 6.1: Each of the representations are compared against qualities like type, interactivity, and real versus modeled or virtual fabric, to outline the differences between each form.

Representations Selected For Evaluation

Initially, we selected all representations to study, due to the different advantages of each for designers. Ultimately in our prototypes of the virtual fabric, we failed in recreating a virtual fabric version of many fabrics we had in real life. Given how important it is to have the best quality representation we could get, we concluded that it would take a significant amount of time and expertise,from a graphics or 3D model artist, to get virtual fabric that behaved similarly enough to the actual fabric for the representation to be useful. So, in order to provide high-quality representations of the fabrics, we cut the virtual fabric interface.

6.1.4 Supporting Ambiguity

Since a designer may have a high or low-fidelity design idea, we wanted to accommodate for the different kinds of ways to find a desired fabric. First, by presenting different kinds of representations on the same page, the designer can compare visual with descriptor information, and determine what makes sense to them. If a fabric does not appear to be shiny, but is labeled as shiny, the designer can negotiate with what they see and determine for themselves whether the fabric is shiny for them.

To leverage the words and descriptors used, we chose to have a search box that can handle single or multiple descriptors, such as “soft, shiny” and comparison descriptor words. For example, if a user picked a fabric, but wanted to see what else was softer, our search box can also find similarly soft or softer fabric. So, our search box can input comparison words when designers want to compare other fabrics to a selected fabric.

Our differential or compare view supports ambiguity by showing fabrics grouped by the same quality, independent of whether there is a agreement over how that quality is used. For example, if two fabrics were similar because both were labeled as “cotton”, and the user is unsure of that label, the user would then have the opportunity to check out similar fabrics labeled as “cotton”, see other representations of those fabrics, and make their own decision on whether that label makes sense to them.

The word-level analysis gave us connections to different words, that can give designers of this system different ideas to think about their fabrics. But, context is lost between at the word level. From the prior expertise studies, there are not many significant differences between everyday participants and experts, on the word level. Another example of this is thinking about how an individual word like “side” could apply to a fabric. At the word level, it may not be clear what that means. But at the phrase level, “side” may be a part of a phrase like “same print on both sides”, or “sticky on one side”. To support designers to better make sense of these fabrics, we also put in our designs ways to show what people have said about the fabric at the word and phrase level.

Limitations in Supporting Ambiguity

Our system also has some limitations in constraining ambiguity. Since RQ3 is about how designers make sense of and negotiate through ambiguity, these designs provide different ways to represent the fabric.

The graph view can show some level of consensus by making more popular nodes appear more prominent in the interface. A designer may simply defer judgment based on what was said about the fabric, or get more data from the more popular descriptors rather than the less used descriptors.

We may also see designers making their own interpretations based on visual representations, and dismiss what people have said about the fabric all together, only trusting what they see. If a designer may not have enough trust in what was said about the fabric, they may interpret ambiguity is a lack of knowledge and rely on visuals only. We tried to avoid this mentality by showing both visual representations and graph at the same time, and powering the search and compare views based on what people have said about the fabric, encouraging users to consider both the descriptors and visuals.

6.1.5 Storyboard

This storyboard shows early, low-fidelity prototype of the system that combines all the ambiguous queries and representations. In summary, the goal is for the designer to find a desired fabric. For our studies, we have a variety of ways to interact and understand the fabric itself. The designer continues to explore and search to find the desired fabric.

Since there are multiple representations of the fabric, we have an icon showing which representation applies, with no icon representing all representations:

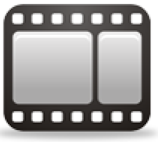
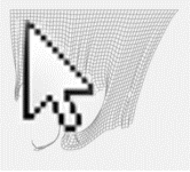
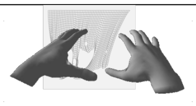
Icon	Representation
	Graph
	Video
	Interactive keyboard and mouse
	Interactive hands

Table 6.2: Icons and their associated representations, placed in the bottom left half of the storyboard pieces.

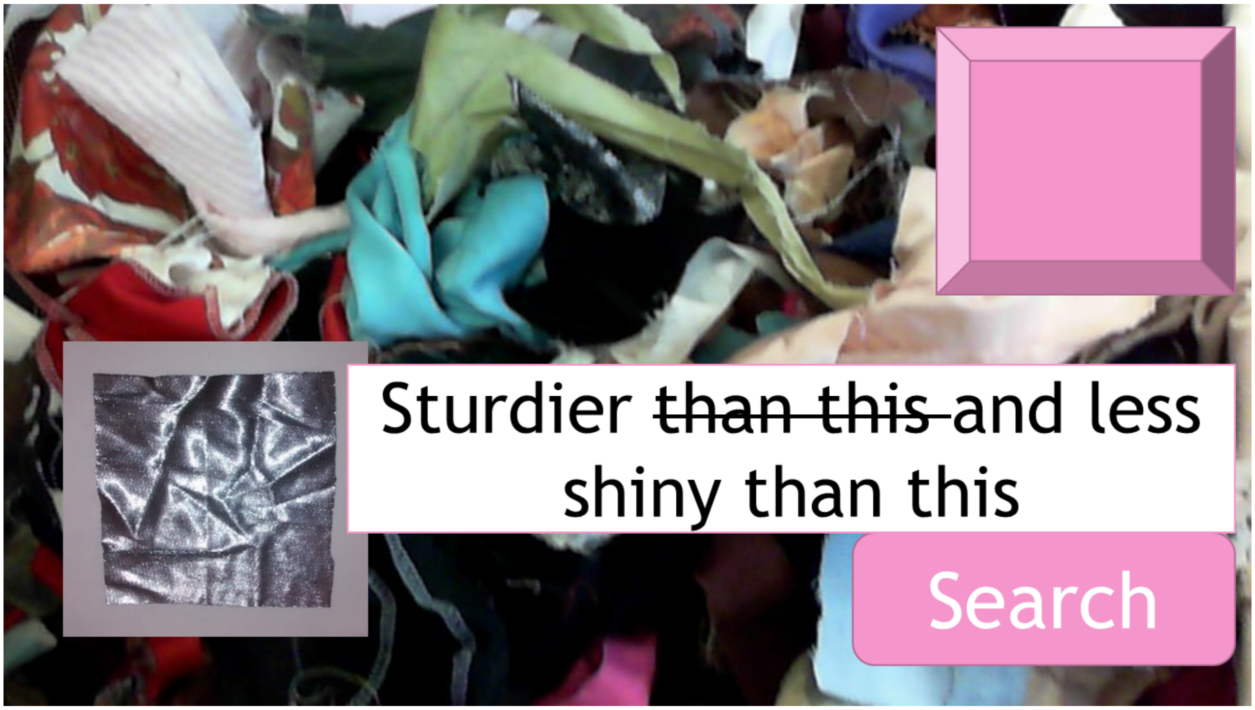
Figure 6.4: The system starts with a fabric bin metaphor, where most of the screen has piles of fabric to explore, a metaphor borrowed from prior studies. The pink box in the upper right hand corner can hold a subset or a cluster of fabric. The box provides a space where the user can put interesting or compelling fabric as they browse. The “Search” button on the lower right side of the screen allows for text input if the user has a specific idea of the desired fabric.

Figure 6.5: The user selects a shiny grey fabric from the fabric pile. If the interactive conditions are on, the user can interact with the fabric to get a sense of how it behaves. If the video condition is activated, a video of the fabric moving, is played on auto-loop. If the graph representation is activated, since graphs are relations to others, a static image of the fabric is shown.

Figure 6.6: The user clicks on the search button and types "sturdier than this", with the grey fabric already selected. This part of the storyboard reveals how a user may be interested in comparing fabrics from one to another.

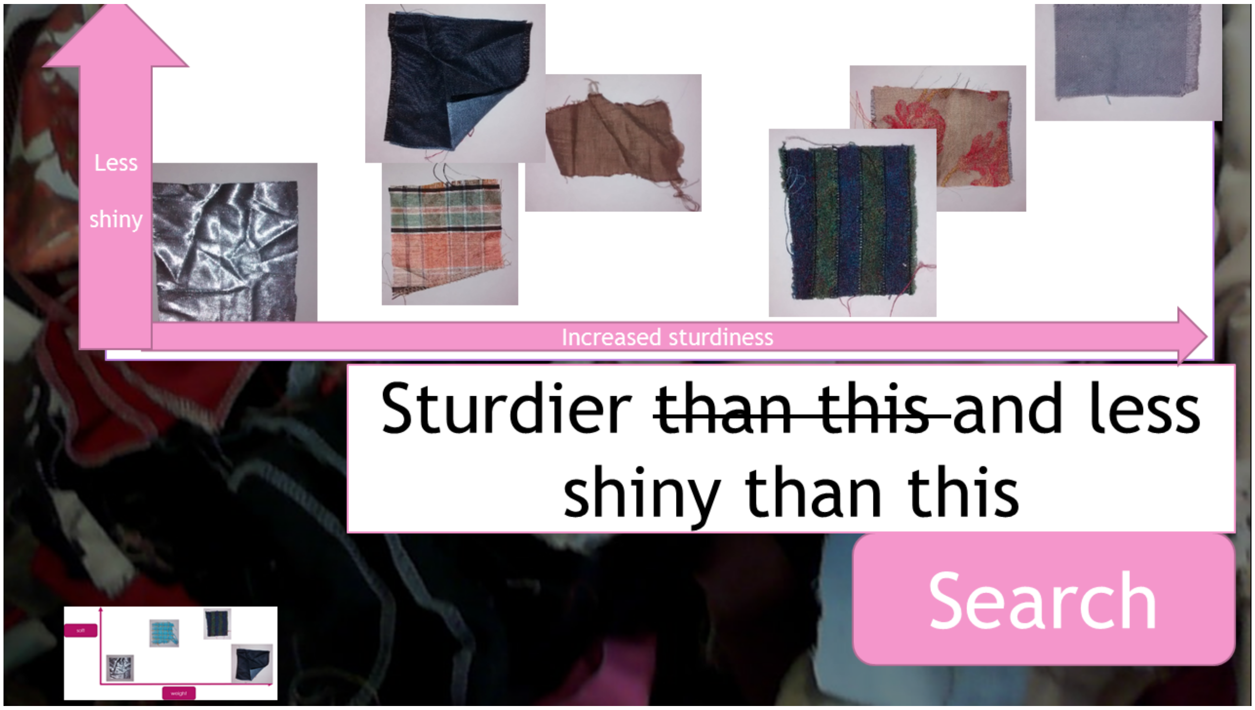
Figure 6.7: Fabrics that are sturdier than the grey fabric are highlighted by popping forward towards the user. This scene is applicable if the video or interactive representations are active.

Figure 6.8: If the graph representation is active, a graph becomes prominent on the screen, showing not only the sturdinesses of fabric sturdier than the selected fabric, but also sturdiness in comparison to each other.



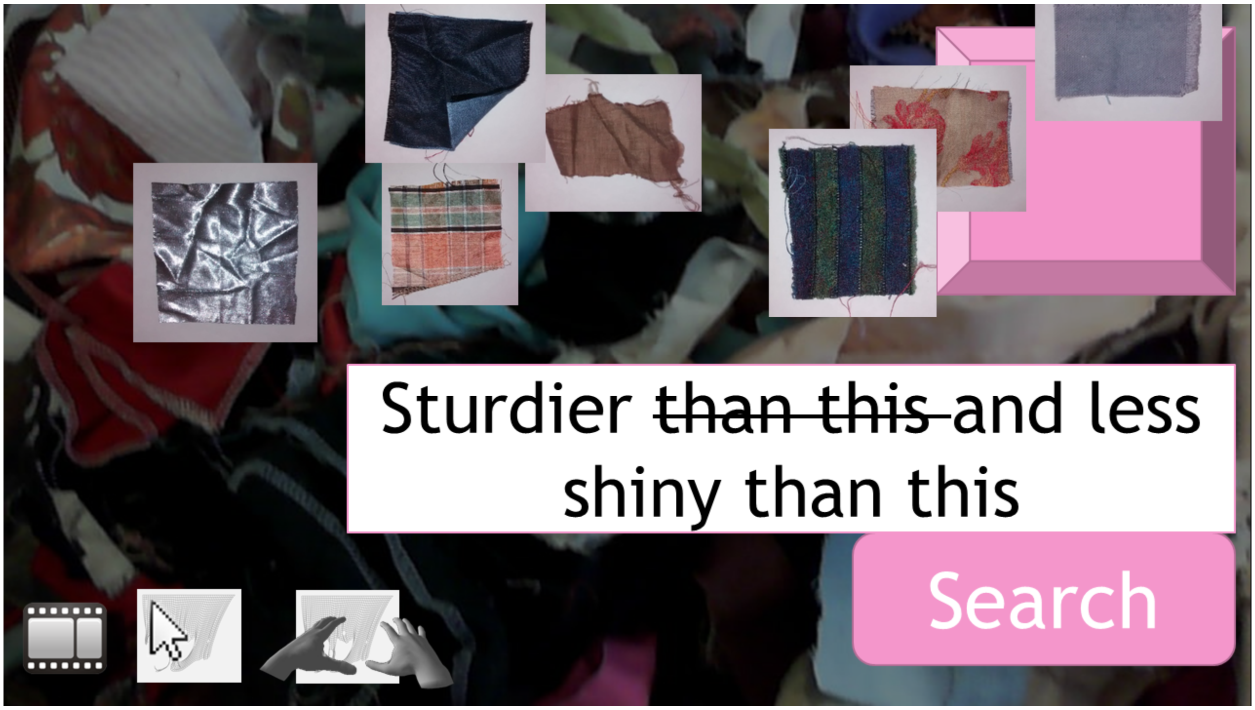
Sturdier ~~than this~~ and less shiny than this

Figure 6.9: The user sees too many choices, and realizes that the grey fabric is too shiny. The user back to the search query. The user deletes “than this” and replaces it with “and less shiny than this” and clicks on the Search button.



Sturdier ~~than this~~ and less shiny than this

Figure 6.10: If using the graph visualization, a new graph appears, with two axes for the two attributes and fabrics that match that criteria.



Sturdier ~~than this~~ and less shiny than this

Figure 6.11: In the video/interactive representations, fabric will appear closer to the user the more closely the criteria are met.

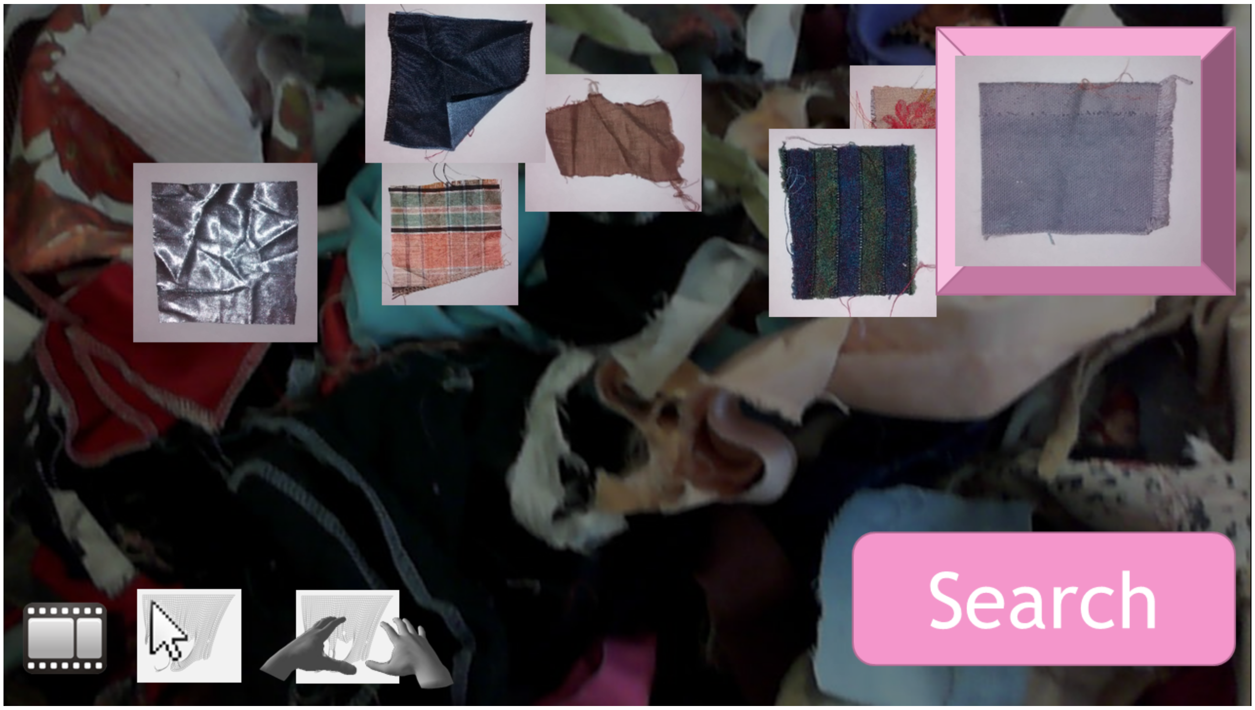


Figure 6.12: The user explores the fabric bin and becomes interested in the grey denim fabric, and moves it to the pink box.

Figure 6.13: While browsing and exploring fabrics, the user also puts aside a brown fabric because it appears to have a desired level of shine.

6.2 Development

6.2.1 Early Prototype

Software

The early prototype was developed on the Unity3D gaming engine[62] and C#. We chose a readily available gaming engine since rendering fabric, the most difficult representation in our system, was already supported in Unity.

Hardware

The prototypes run and were developed on on a Microsoft Surface Pro, as detailed in section 3.1.6. For the interactive hands condition, we used a Leap Motion as an input to detect hand movements.

Prototype Details

This system and its various features were in development, in part, to see whether the platform selected can accomplish all the features desired, such as fabric interaction and modeling of virtual fabrics. We developed live demos of the features below.

Search

The search prototype screenshots below show how we envision search for a description-only query: an auto-complete textbox with drop-down descriptors as suggestions. As the user selects multiple descriptors, applicable fabric moves closer to the user. Below is a series of screenshots to illustrate the workflow for search.

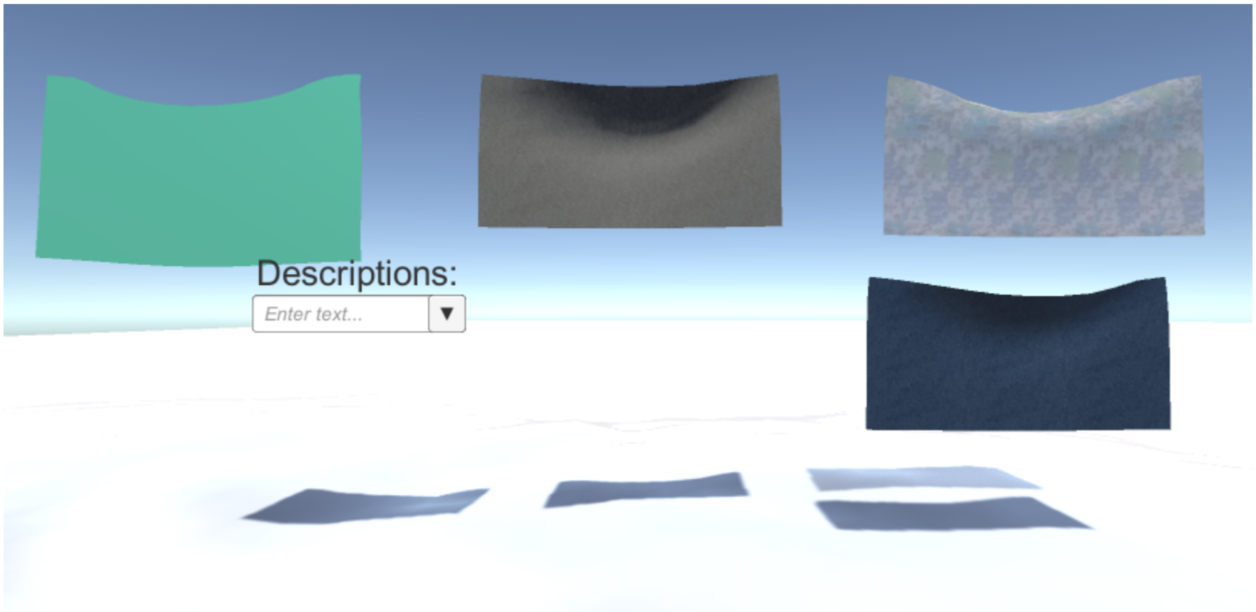


Figure 6.14: The first screen for search, with a selection of fabric in the background, and a search box in the foreground.

Figure 6.15: Screenshot of the menu after the user begins to type a letter, showing suggestions.

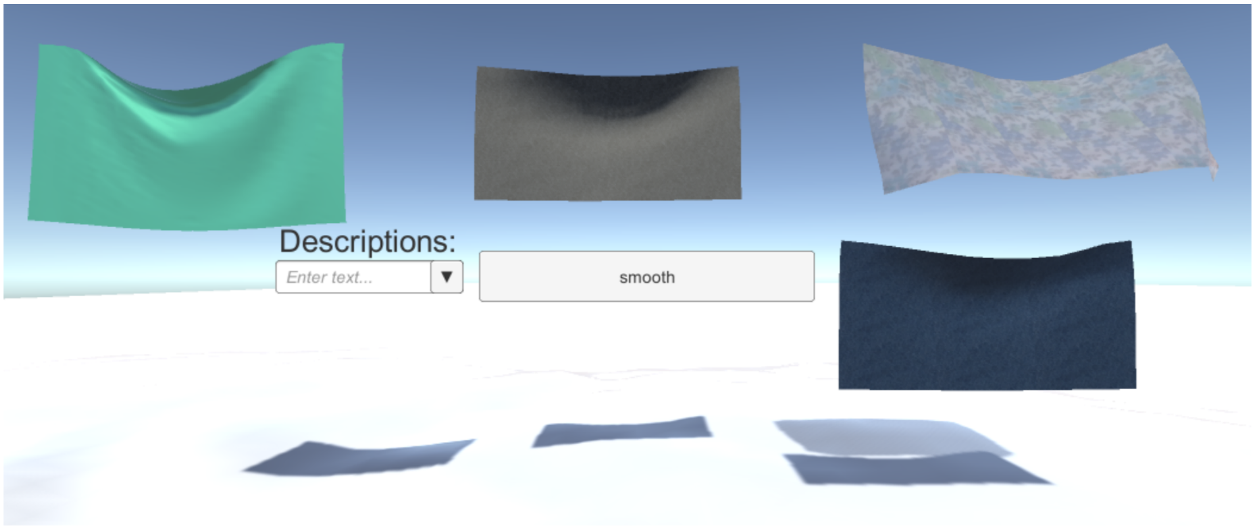


Figure 6.16: After typing in “smooth”, three fabrics that match the descriptor move towards the user.

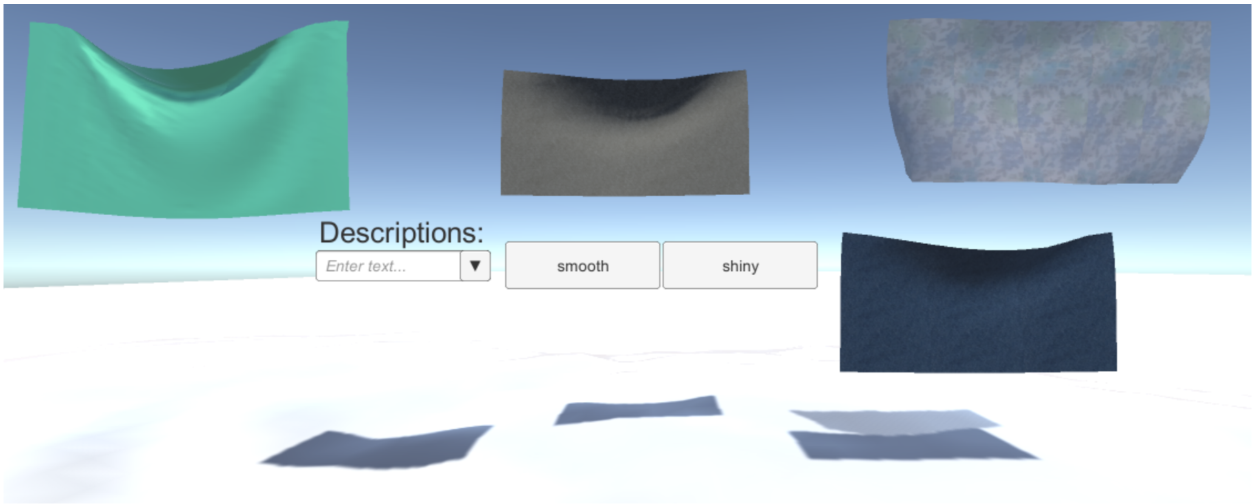


Figure 6.17: After typing in “shiny” into the search query, two fabrics that are both shiny and smooth move forward.

Selection

As shown in the search prototype screenshots above, as fabrics become more applicable to the terms, the closer the fabric approaches to the user.

Above in figure 6.18 is a screenshot that uses wind blown from the left side of the user, to indicate highlighting, with fabrics meeting the criteria getting hit with more wind. The animation already shows how the fabric behaves, so the wind cue is a promising to highlight or select a fabric.

We experimented with increasing the scale of the modeled fabrics, but in our observations, the cue was not visually apparent, and we had concerns over larger fabric completely occluding other fabrics.

Fabrics modeled

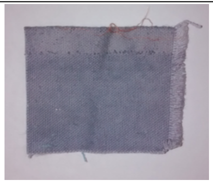
		
		

Table 6.3: The real-world fabrics modeled by the virtual fabric in figure above, in the order appearing in the virtual fabric.

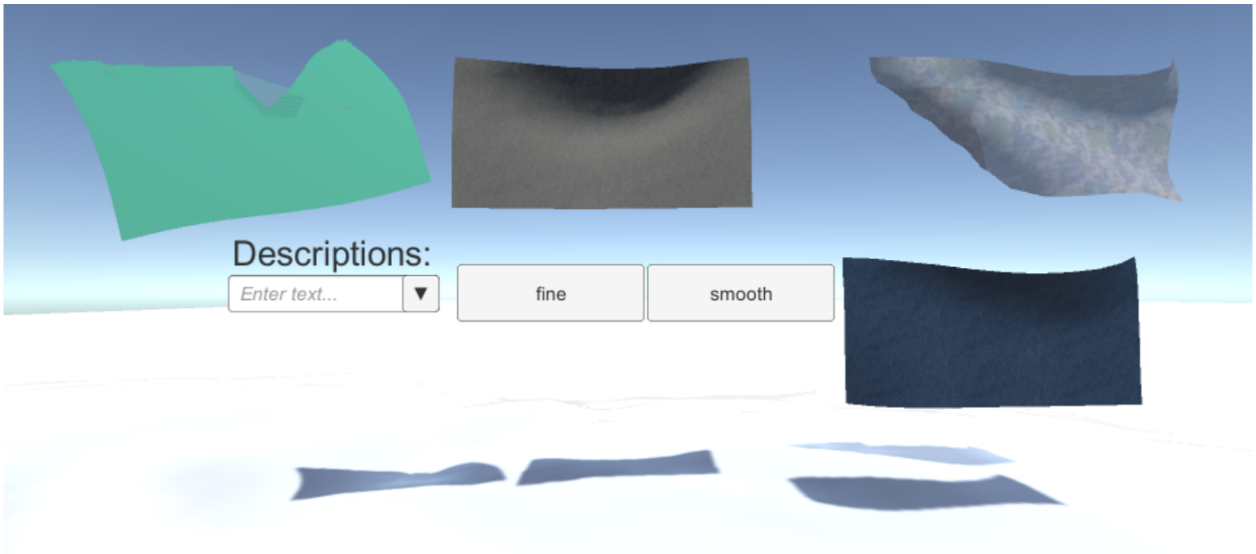


Figure 6.18: The search prototype, with wind blowing on selected fabrics. The faster the wind blows, the more the fabric applies to the criteria.

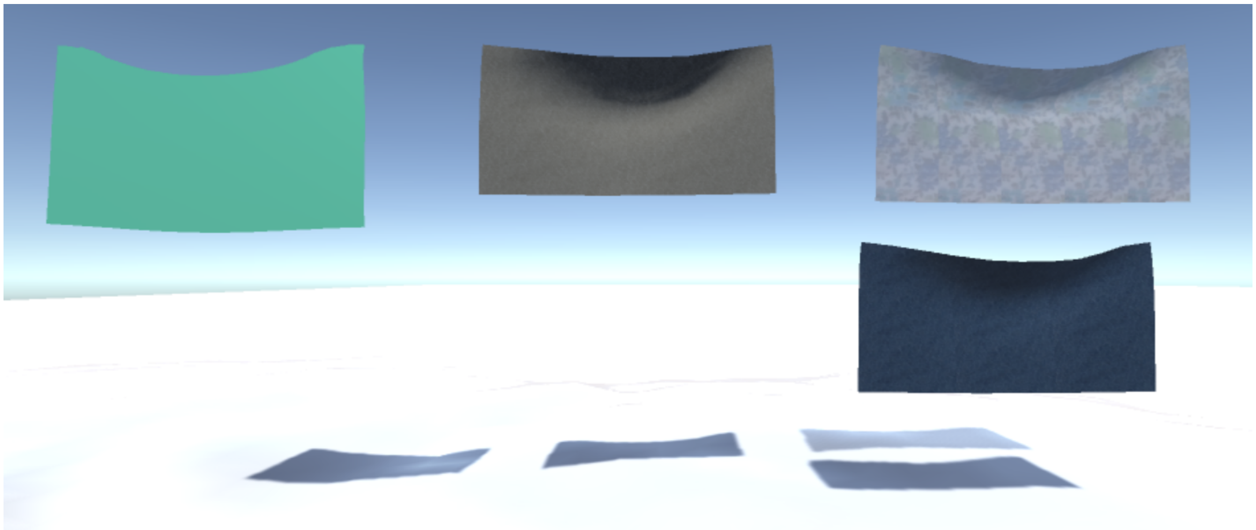


Figure 6.19: The selected virtual fabric above was a large part of our prototypes to see if various different kinds of fabric could be modeled onto the software platform. Each fabric hung on two points on the upper left and right hand corners. The real-world equivalent fabric is in the figure below. The fabrics with the most drape, the upper left and upper right, both have the biggest curve.

We initially chose fabrics that have unique qualities that would be challenging to model, and pairs that are similar to each other. In our prototypes, we started with a shiny satin to test fabrics with a shine and drape to them, a patterned sheer mesh to try transparency with patterns, and a pair of denim fabrics with different hands, drape and weight. We modeled these fabrics virtually, as seen in figure 6.19, and their real world equivalents in table 6.3.

Interactions of fabric

In figure 6.20, is a screenshot of interactive hands-on fabric, using the LeapMotion to display a robotic hand that fades in and out based on tracking accuracy. We experimented with different hand appearances, including realistic ones, but found that realistic virtual hands looked too jarring if the virtual hand's skin tone did not match the user's. We decided on an unrealistic robotic-style hand to resolve that problem.

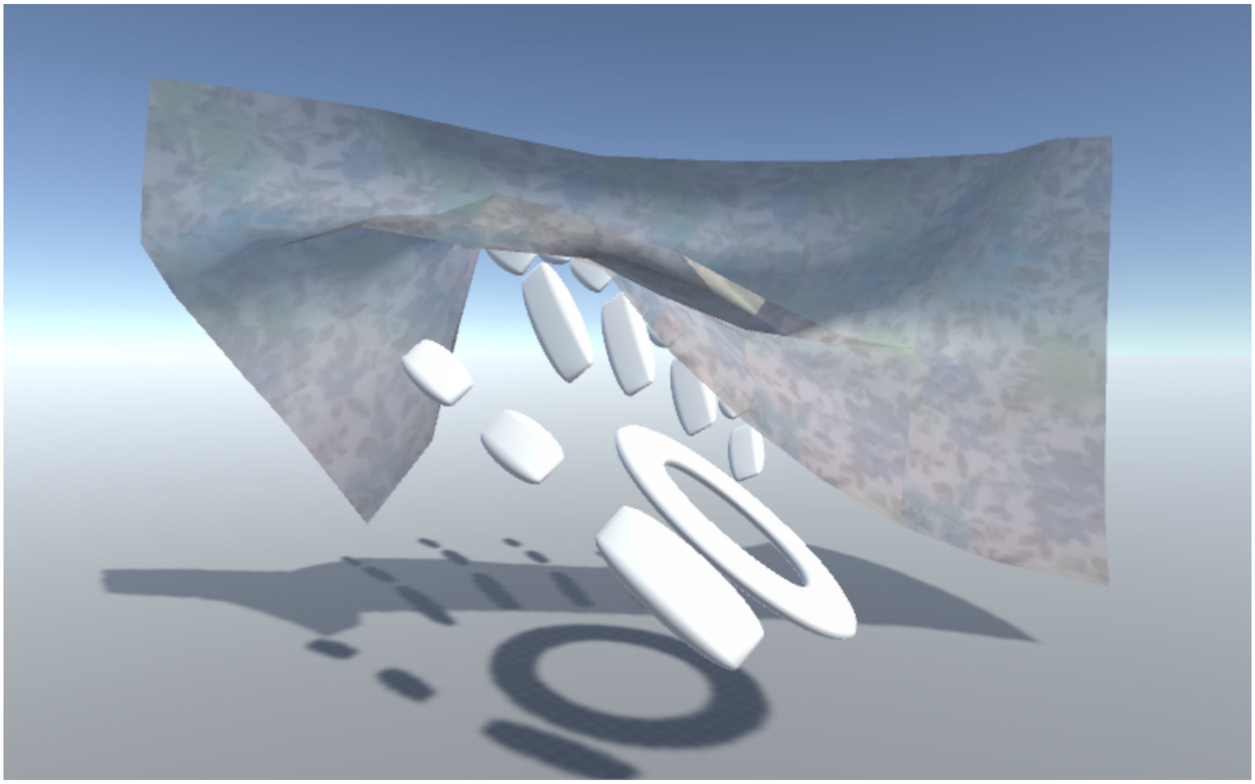


Figure 6.20: In this screenshot, a virtual robotic hand appears and moves the fabric, with each finger fading in an out based on tracking accuracy and visibility.

Change in Platform

The prior prototype had some virtual fabrics modeled after real-world fabrics. But, the virtual fabrics still did not look like their real-world counterparts. Given that professional-level 3D modelers, graphics artists would be needed for a close one-to-one match, along with the corresponding software, we felt that it would take years to get high-quality virtual fabrics that match their real-world counterparts. So, we decided to remove the virtual fabric portion of the study.

Without the virtual fabrics, Unity, a 3D gaming engine, lost its core advantages, with the additional disadvantages of custom game-focused user interface toolkits.

6.2.2 Early, 2nd Prototype

We switched to developing on Windows apps. Since the app just needed to run on one laptop, any native app on a machine would provide common UI toolkits to execute the designs. This prototype was not interactive, but was meant as a proof of concept to see what we could built that matches closer to our designs.

Below figures shows some of the first designs implemented. Figure 6.21 shows the bin view, and clicking on any fabric will bring them to figure 6.22, or the detailed view of that fabric. The semantic network design is in figure 6.23, with an earlier design where users select desired qualities from a list. The compare view is in figure 6.24.

After developing this prototype, we found that while the core UI toolkits were easy to incorporate, anything beyond that would haveto be built myself. If we wanted a graph of words (as opposed to a chart), there was little support natively supported or in the development community. We also ran into speed issues in running our prototype, and were concerned when we added the rest of the content.

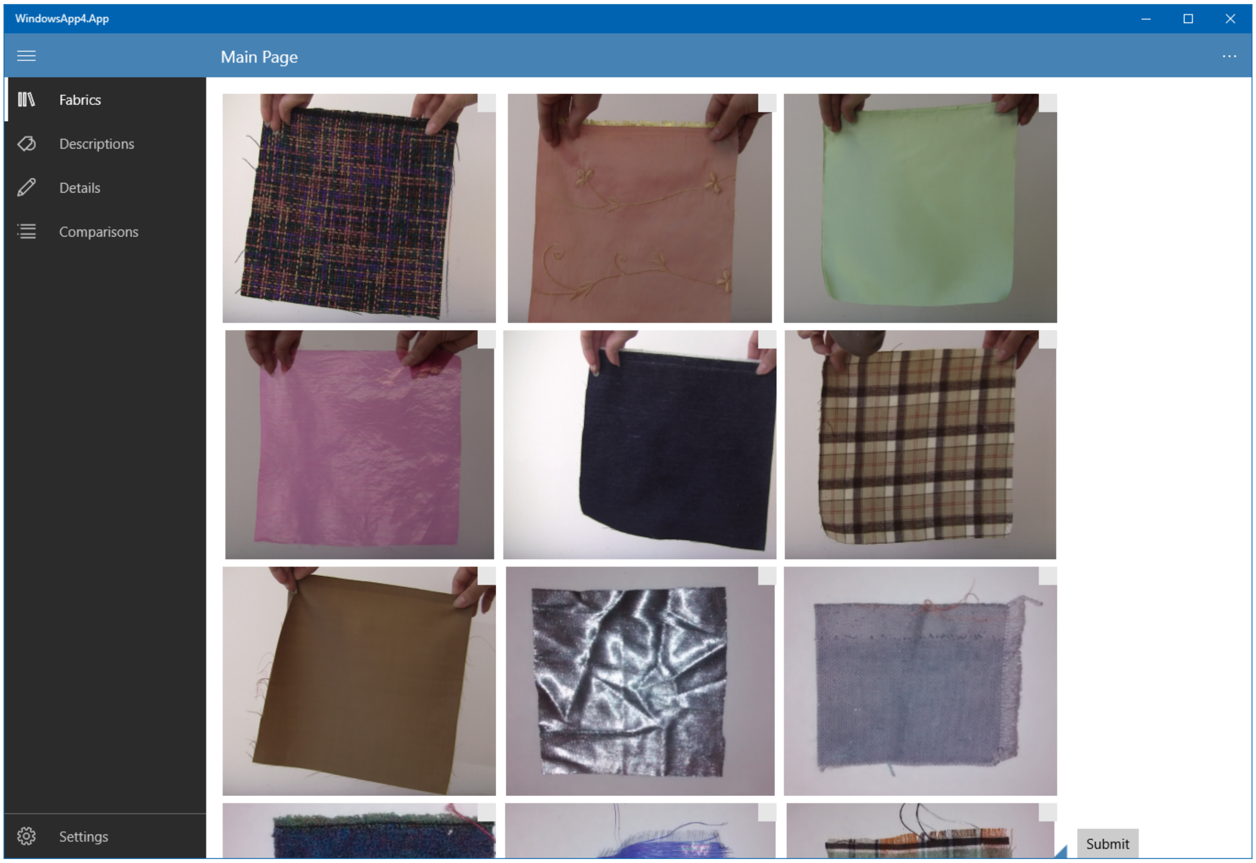
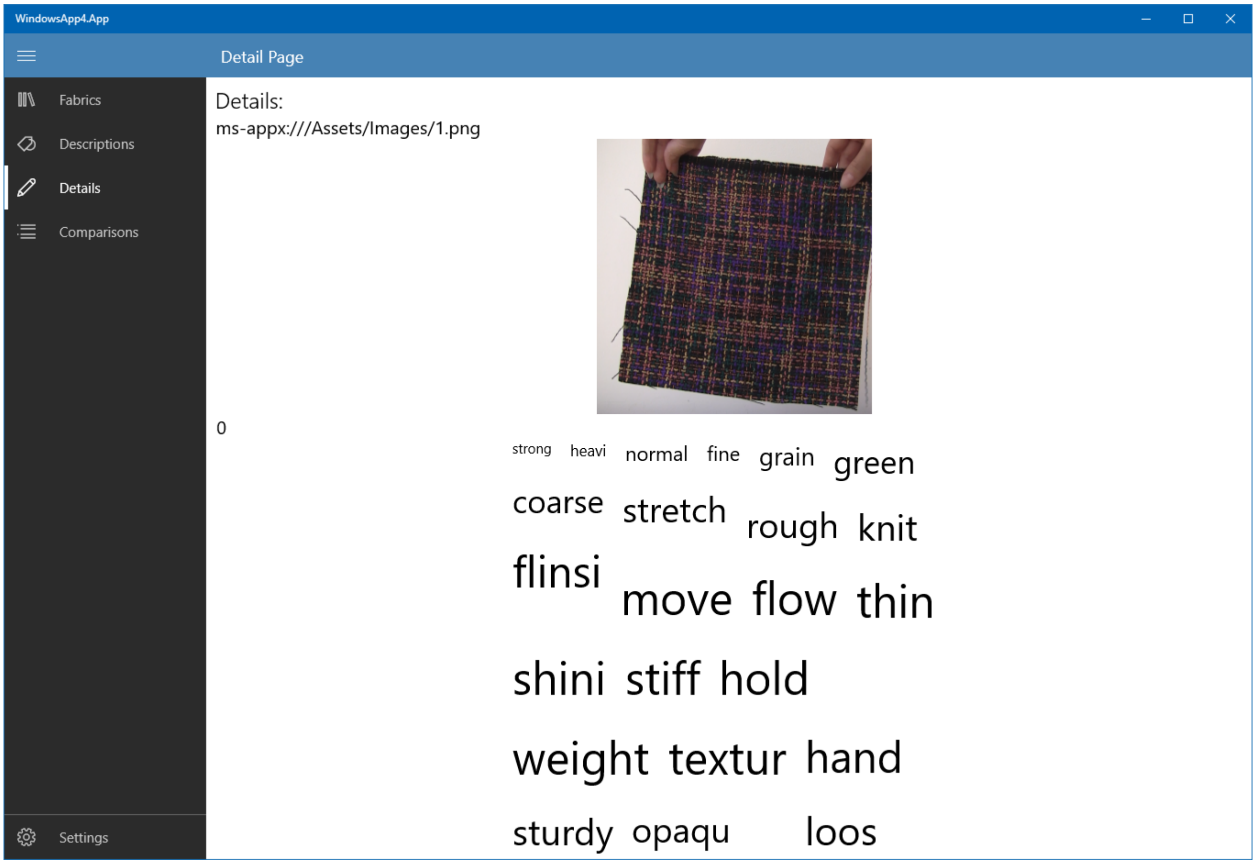


Figure 6.21: The Fabric Bin design in a Windows apps prototype. Nine fabrics are immediately visible, with a menu on the left-hand side.



Details:
ms-appx:///Assets/Images/1.png

0

strong heavi normal fine grain green
coarse stretch rough knit
flinsi move flow thin
shini stiff hold
weight textur hand
sturdy opaqu loos

Figure 6.22: The detailed view of one fabric, under the Windows App prototype. An image of the fabric is shown, along with a list of root words of descriptors used on that fabric. Text size shows how often that word was used.

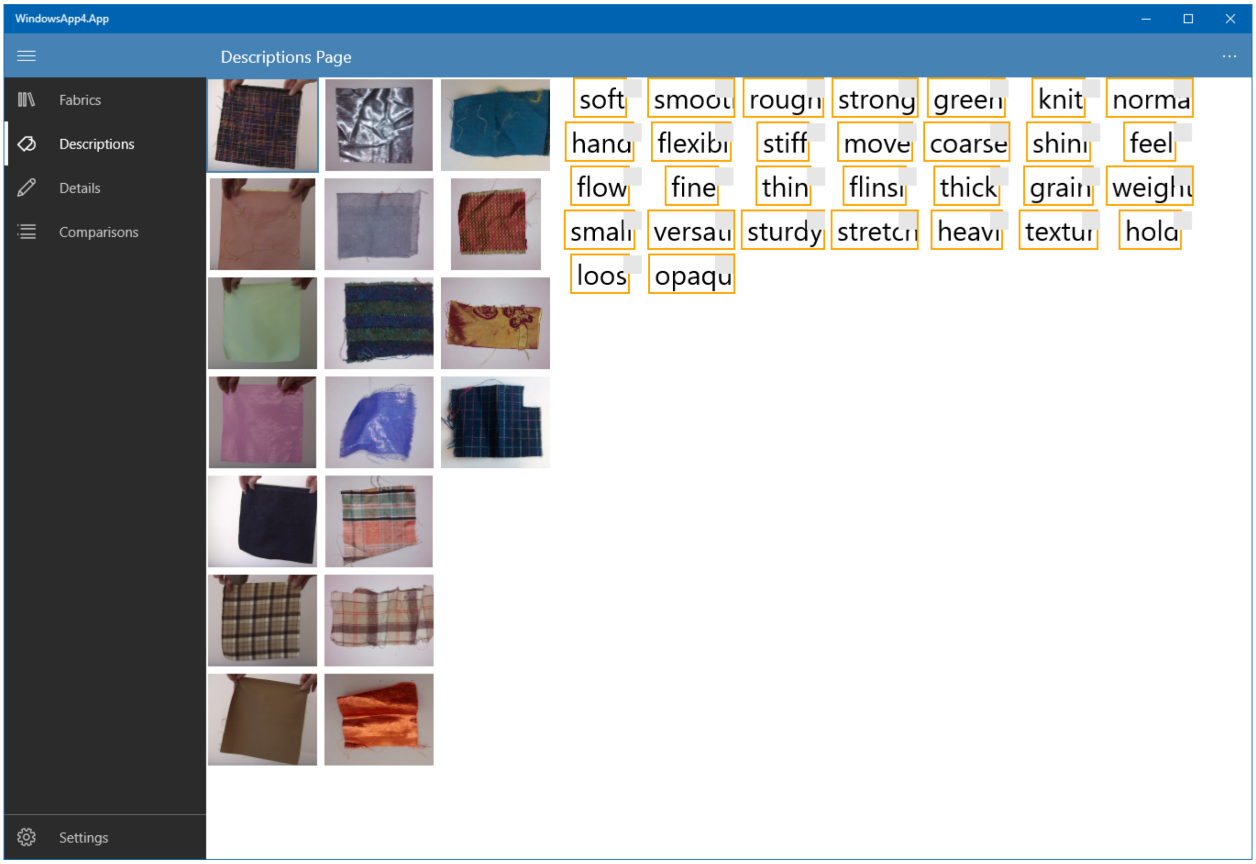
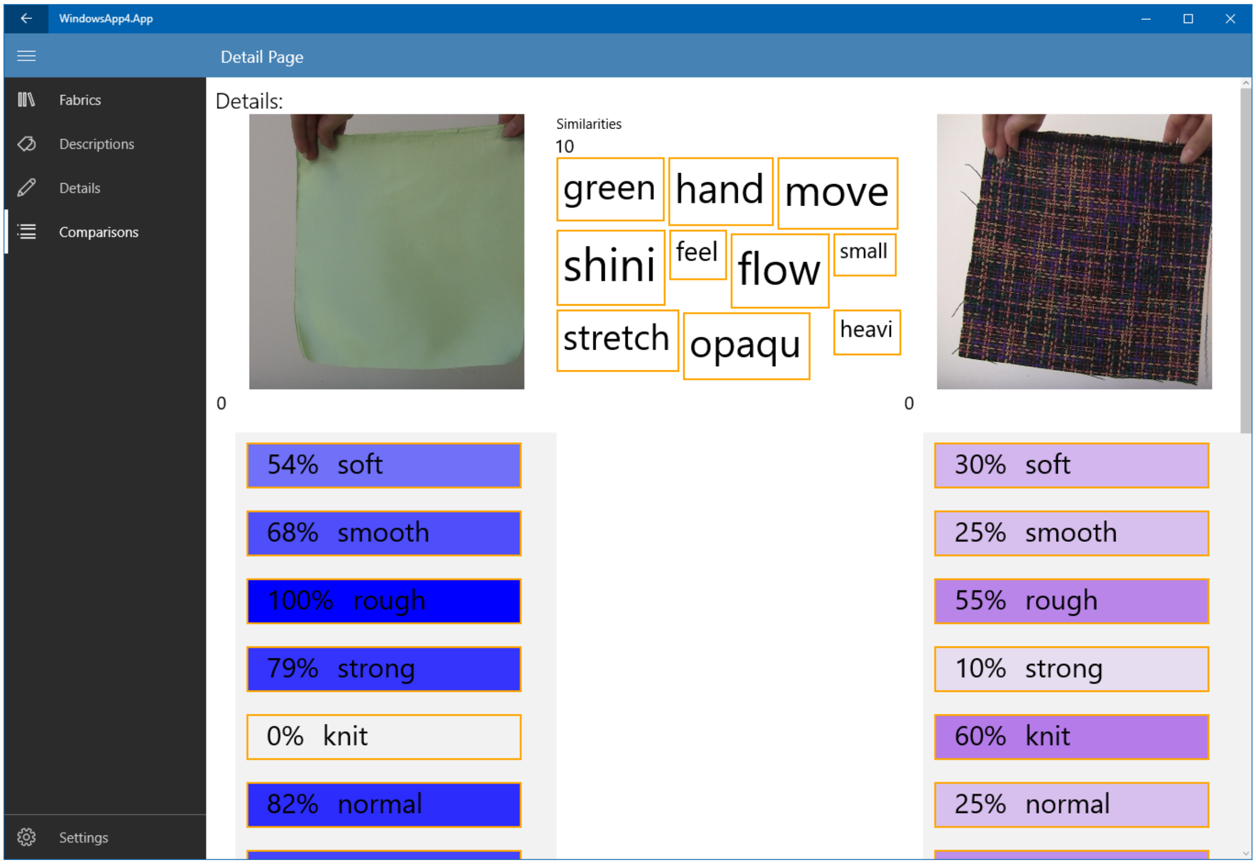


Figure 6.23: The semantic network design on the windows app prototype. In this iteration, the user clicks on the check mark of desired fabrics, and the list of fabrics on the left changes to show those matching all the qualities.



54% soft
68% smooth
100% rough
79% strong
0% knit
82% normal

30% soft
25% smooth
55% rough
10% strong
60% knit
25% normal

Figure 6.24: The image shows the compare design on the windows app prototype. In between the two fabrics, we see qualities that both fabrics have similarities with. Below each fabric are a list of qualities and how many people have used that quality.

6.2.3 Mid Prototype

Given the increasing disadvantages of developing on Windows, we switched to another development platform, Under strong recommendations that the designs could be accomplished on the web, the mid-prototype was developed in AngularJs 1.5, a popular platform that employs javascript and HTML.

The screenshot below, figure 6.25 was a snapshot of the proof-of-concept interface developed, to see how well were graphs supported in the web platform, with a dummy dataset. The lefthand side relied on many example tutorial code, while the righthand side was rendered using vis.js. With the ease of coding up a graph, we continued to use vis.js for any graph visualizations from this point onward in development. The only challenge in developing in the platform were challenges in speed.

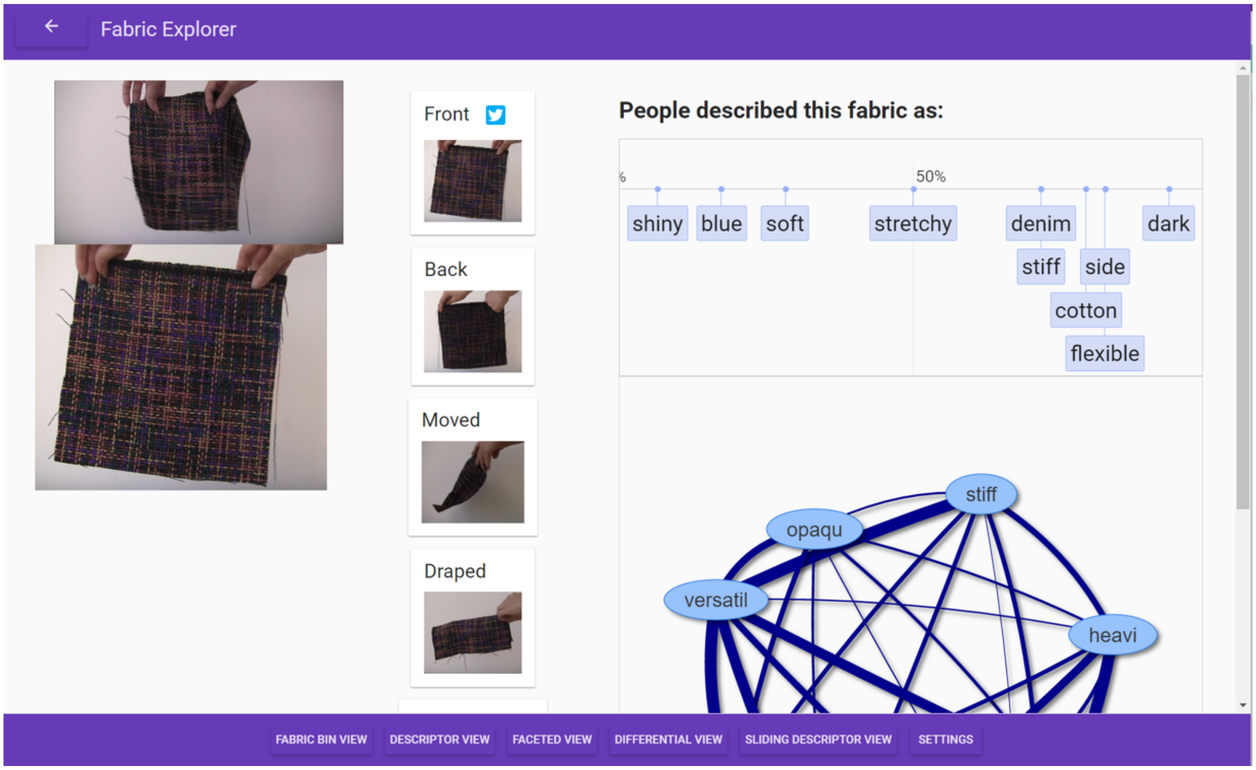


Figure 6.25: Snapshot of the detailed view from the first prototypes in AnglarJS. Thumbnails of the images are on the left hand side of the screen, while descriptions are on the right. The first visualization showed how a percentage of how many people used that keyword. Below the graph is an example of a co-occurence graph.

6.2.4 Data Sources

This system needed to support two kinds of information:

1. Visuals: Images and Video
2. Descriptors: Graph of words along with supporting data for search and compare views.

Below shows a section for processing each piece of data.

Rerecording and Post-Processing Videos

We re-recorded all the videos, since new ones were added in and we wanted to keep a uniform recording setting for all fabrics. Figure 6.26 shows the recording conditions for the videos.

After recording, the videos still appeared to have dim lighting, despite the efforts of different lighting setups and arrangements while recording. We used Adobe LightRoom while having the fabric side-by-side, to match the fabric to what we saw. After doing these comparisons, generally, the brightness and exposure needed to be increased one stop, and contrast needed a slight increase.

Images for the front and back along with the gathering, movement and draping gestures were all individually extracted from the videos. The close-up view was a new addition suggested from the second crowdsourcing study, so we shot each close-up image of the fabrics with a black background, to provide a different background than the white background videos.

There were a series of tweaks done to the system to improve performance on the system. There was additional scripts that changed formats and sizing. This was needed since the images initially were full size and loaded too slowly. The videos were uploaded to youtube and the right resolution and quality needed to be set on the system side. Fortunately, youtube partially adjust the quality and resolution automatically, so there was no need to resizing to be done manually.

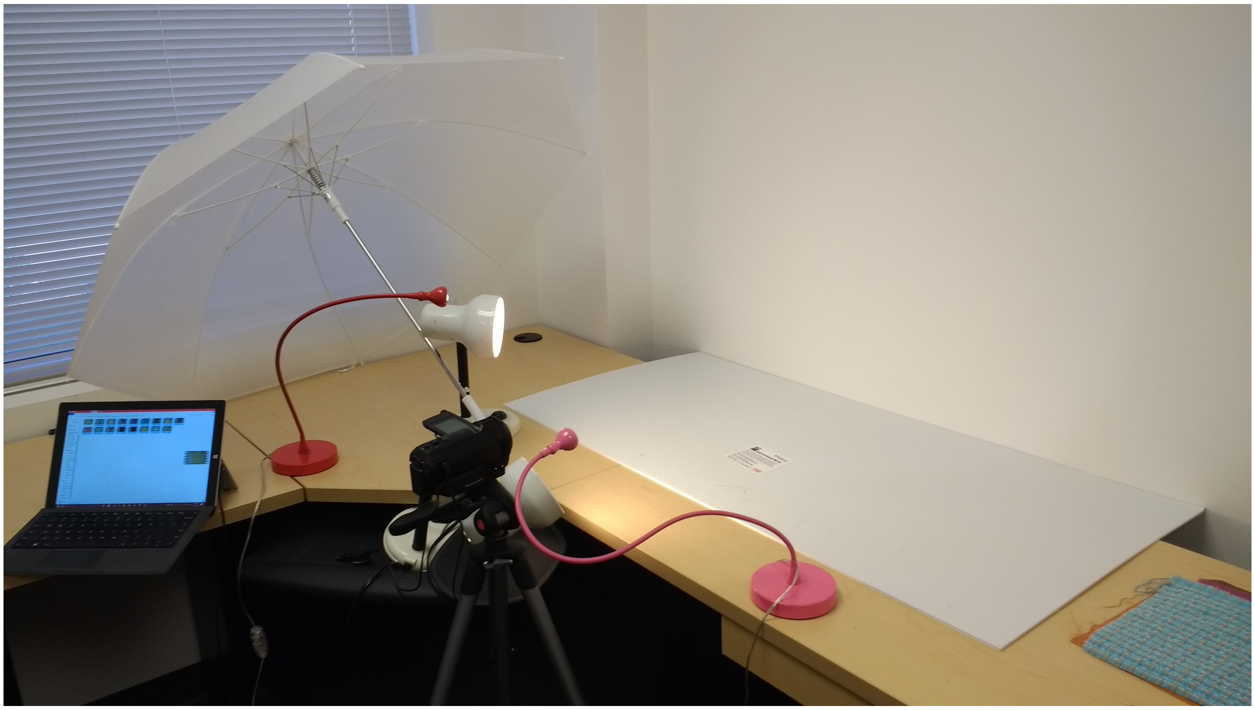


Figure 6.26: This figure shows the recording setup, with the use of lamps, lights and white backgrounds and umbrellas, to project as much light to the fabric as possible. The sun was blocked out because it did not give uniform lighting for recording all 45 fabrics.

Processing Descriptors

The processing for the system is different from the ones done before. While it built upon the prior work, there were a few key differences.

The first differences is that any categories that were helpful in prior studies needed to be undone. The biggest example of this is color. In prior studies, references of color were placed in the same category to get a sense of what participants noticed about the fabrics. For this system, however, it was imperative to have each color count as its own descriptor.

The second difference is translating the difference of negation of a descriptor. In the dataset we saw references for “isn’t stretchy”, “not stretchy”, and “no stretch”. We wanted to preserve this information because it’s reasonable for someone to not only mention that in the dataset, but also think in terms of what they do not want.

The designs included a search area where users could type what they do not want, but while we could have treated the “no stretch” quality the same as “stretch” in the exclude search box, we concluded to allow “no stretch” to be processed as its own descriptor. It’s valuable for the user to see that others have described fabrics with the word “no”, and that some users have explicitly described the absence of a property.

This meant processing “no stretch” as a unique term for most of the processing. Keeping “stretch” and “no stretch” meant keeping those terms as distinct and separate terms throughout the system except for co-occurrence graph generation, since co-occurrence is at the word level, not phrase level. R scripts were made to convert any words that meant negation (“isn’t”, “cannot”, “not”, etc), converting them to “no-” with a dash so that the no is not lost in processing, and then replacing the dash for a whitespace later so that it had the phrase looked grammatically correct.

The descriptors needed extra processing in different forms. Below are a list of the pieces of information needed:

1. Co-occurence graph for graph of words. We needed a co-occurrence graph for generating the graph of words and for the search system to give relevant suggestions.
2. List of all the descriptors used in the dataset. This data was useful for search and providing a list of words as the user typed.
3. Look-up table from fabrics to descriptors to check how many times particular word was used to describe the fabric.
4. Look-up table from descriptors to fabrics, to check how many times the descriptor was used for the fabric. The search view used this table to aid in sorting.
5. Look-up table from fabric to descriptors, containing phrases that contained the descriptor. This table was used for the detailed view to provide context.

Each one of these pieces were converted to its on comma-separated list, or .csv file. Then each one was converted to a json file, a common data format for the web.

6.2.5 Design Changes with the Data

Once all the data was processed, the data was added into the system, replacing dummy data we had. There were significant differences between our dummy data that caused us to rethink our designs.

The first challenge came from processing the data to include the “no ” descriptor. The design challenge became: How should the search view report the results for a descriptor in the include? How does the negative descriptor play into the search results, even if the user did not include the negative descriptor in their search?

Initially the search worked by the percentage of people mentioning that quality. Fabrics with the qualities mentioned scored higher than those without the quality.With some iterations in the search, the ranking algorithm that made the most sense was the following to calculate its ranking:

1. **Add** to rank, the percentage of people mentioning each qualities in the **include** search box to rank. (+“stretch” as a quality to include)
2. **Subtract** from rank, the percentage of people mentioning the negation of qualities in the **include** search box to rank. (-“no stretch”)
3. **Subtract** from rank, the the percentage of people mentioning the qualities in the **exclude** search box to rank. (-“shine” as a quality to exclude)
4. **Add** from rank, the the percentage of people mentioning the qualities in the **exclude** search box to rank. (+“no shine”)

The second challenge was about the lack of consensus of the actual dataset and how that quality is a mismatch to the dummy dataset. To illustrate, figure 6.27 shows what the dummy dataset showed for a particular fabric. One would expect that most, if not all people describing a fabric would mention the fabric’s most salient quality and that there would be some level of consensus. In the figure with our dummy data, nearly 90% of people mentioned the word “dark”, along with around 75% of people using words like “denim”, “stiff”, “cotton”, “side”, and “flexible”.

Once the dataset was processed, the reality was that there was very little consensus in the kinds of terms used. For some fabrics, the most used quality was used by 50% of people, with very rare cases hitting 70%. The vast majority of qualities fall in the 1%-30% range. This lack of consensus is due to the unclear and limited vocabulary in the design domains. Someone may call a fabric “dark” while someone else may call it “black”, “dark blue” or even “midnight”. While we anticipated this lack of consensus, it was actually surprising to see how little consensus there was in terms.

The visualization in figure 6.27 would not work for the kind of dataset we had. If visualized, it would have one or two qualities at 50%, and 40+ descriptors closer to the 3%, for example. So, we removed this visualization altogether, and visualized the percentage with sizing of the node in the graph, along with providing extra information when a user hovers over a node.

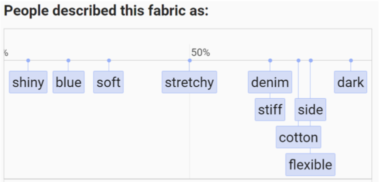


Figure 6.27: Screenshot of the detailed view in the midway prototype, the descriptor portion of the view. Qualities were graphed based on the percentage of people using that quality. Qualities towards the left-hand side were mentioned less than those on the right-hand side.

6.3 Final System Walkthrough

This section is a walkthrough of the resulting system, including some of the less crucial but important design decisions that helped shape the final system. This walkthrough is organized per view, or page.

6.3.1 Views

Fabric Bin

Figure 6.28 shows the final version of the fabric bin view. All 45 fabrics are visible when on full-screen on the study machine.

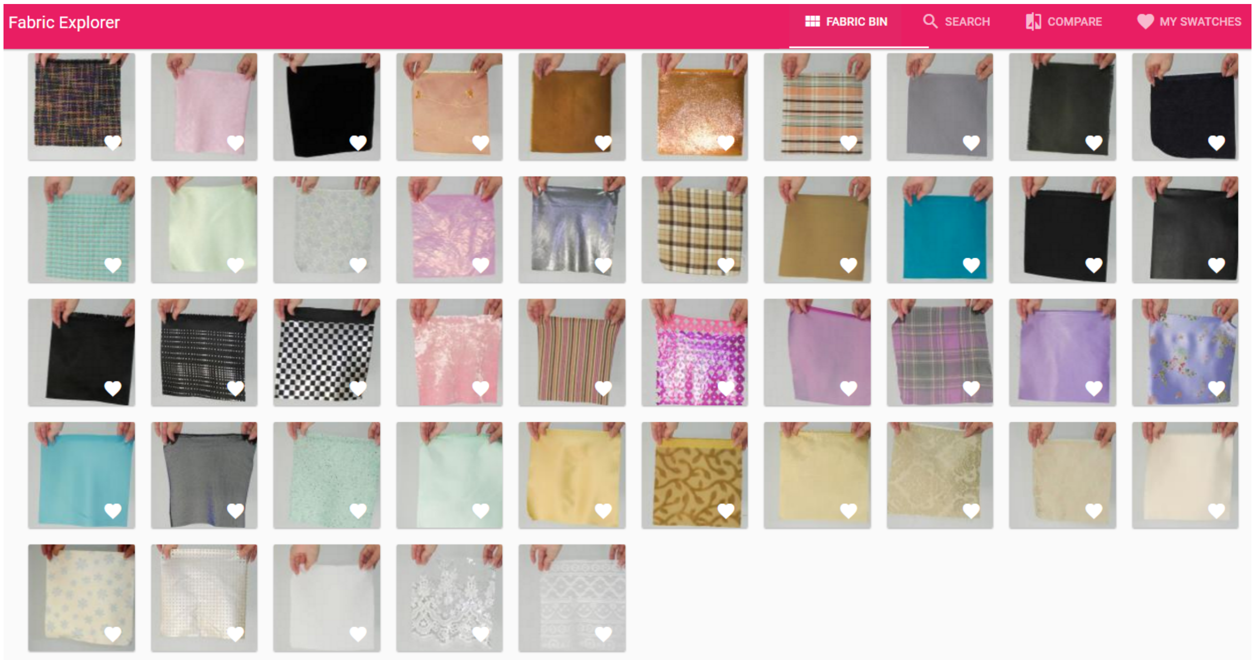


Figure 6.28: The final version of the fabric bin view, with 45 different fabrics all visible.

Each fabric has a heart button next to it. If clicked, the system marks that fabric as one to show in the "My Swatches" section. It also changes the button's colors to have a pink outline as shown in figure 6.29. This visualization is present and persistent throughout the system so a fabric marked in one view still has the same visuals in all views. This state is persistent so that it can be used however the user may like, such as marking fabrics of interest and narrow them down, or exclusively mark fabrics of interest with the heart button. There is no limit to the number of fabrics that can be marked.

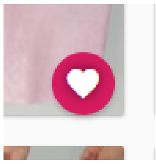


Figure 6.29: When a fabric's heart button is pressed, the icons changes to have a pink circle, to indicate that it's active.

My Swatches

If a fabric is marked, the fabric/s end up in a "My Swatches" view, as shown in figure 6.30. This view is provided as a view that only shows the most important fabrics to the user, removing all unmarked fabrics.

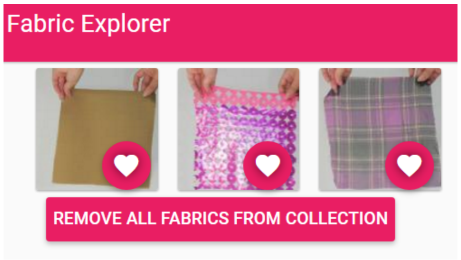
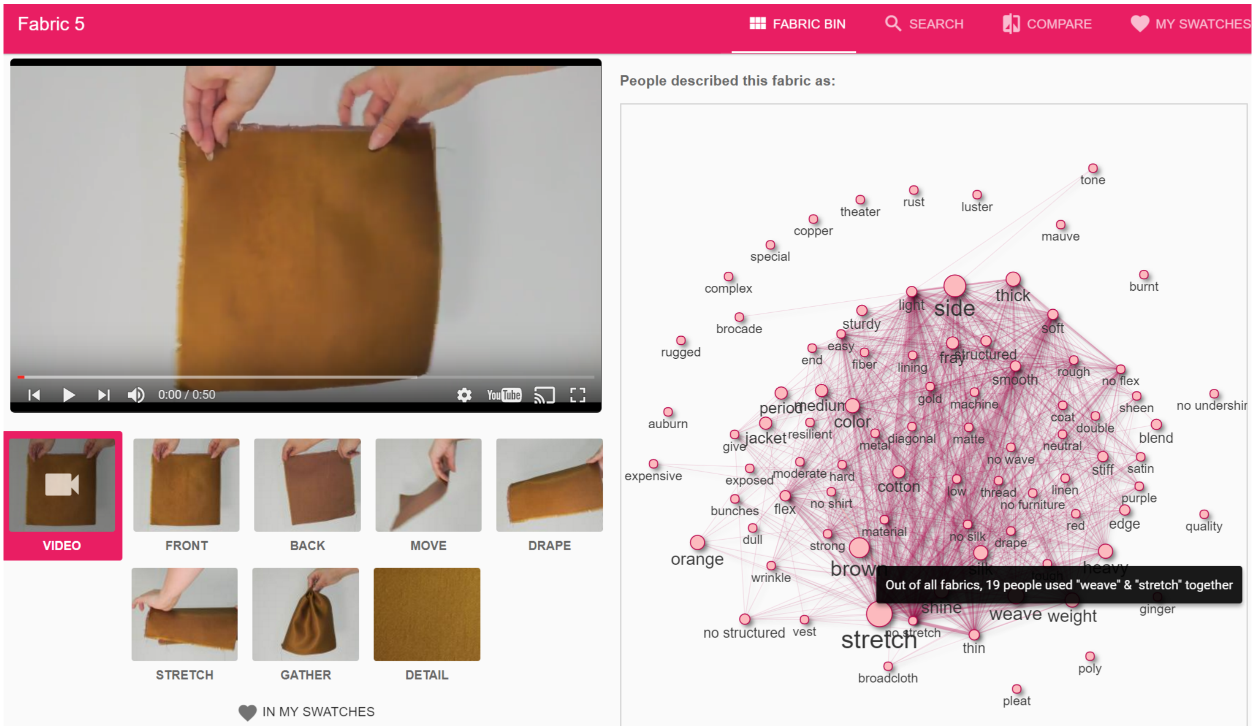


Figure 6.30: When a fabric's heart button is pressed, the fabric is shown in this view.

Detailed

Figure 6.31 shows a screenshot of the detailed view of the system, with two different kinds of information put side-by-side. The left hand side has visual-temporal information about the fabric, in the form of images and video. The right-hand side shows what people have said about the fabric. We describe the detailed view with respect to each side.



People described this fabric as:

Out of all fabrics, 19 people used "weave" & "stretch" together

Figure 6.31: Screenshot of our system's detailed view of a fabric. The left-hand side are visual-temporal data with images and video of the fabric, and the right-hand side shows a co-occurrence graph of what people have said about the fabric.

Left-hand Side: Images and Video

The video autoplays in the large frame in the upper-right hand side of the screen. Since the prior studies showed value in the video, it was selected to be shown and played first and automatically. A bit of coding helped assure that the video always played the highest quality, automatically, and auto-looping if the user did not click on another image.

If the user clicks on any thumbnail below the bigger view, the bigger view swaps for what was selected, to provide a closer view of any of the images and video. Figure 6.32 shows the different kinds of views that the user could select for the fabric.

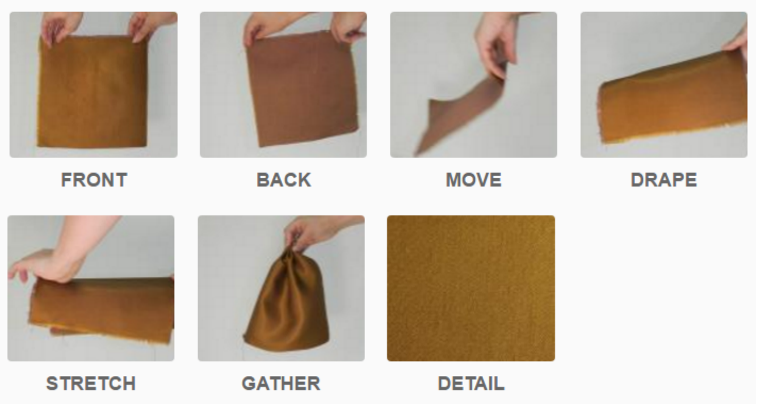


Figure 6.32: The screenshot shows thumbnails of different images and video that are selectable in the detailed view of the fabric.

The last piece of the right-hand side is a button to include or remove the fabric from the "My Swatches" collection, to support that persistent feature throughout the system.

Right-hand Side: Descriptors

Figure 6.33 shows a co-occurrence graph of all the words used to describe the fabric. A co-occurence graph is present so that users can explore and get ideas from related of co-occurent nodes. Any of the links and nodes are selectable. The size of the node indicates how many people have used that particular term, and the graph even includes descriptors used only one, to reflect that one descriptor said by one person may be enough to spark an idea for the user. The graph is also moveable and draggable as well so users can explore, move and push nodes in any desired direction.

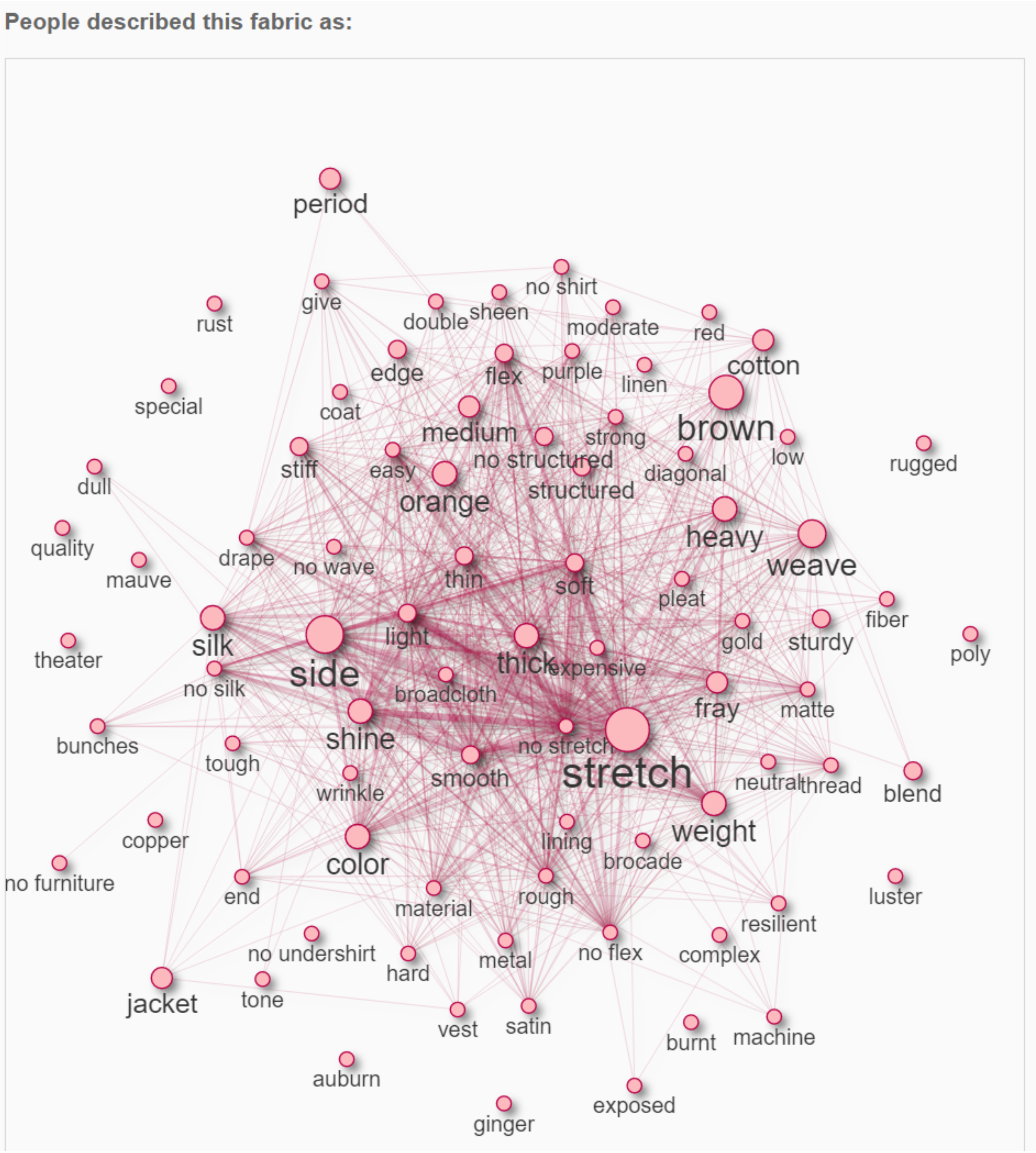
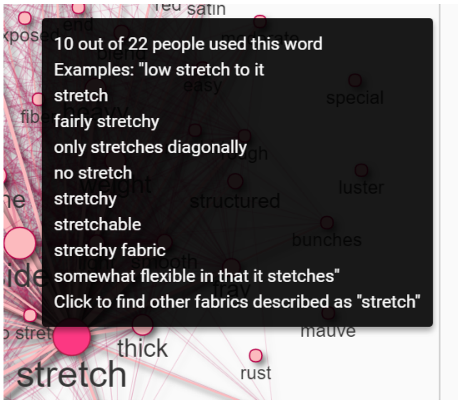


Figure 6.33: Screenshot of the right-hand side of the detailed view, showing a co-occurence graph of what people have said about the fabric. The graph is fully interactive, as it can be dragged, moved, selected, and clicked on.

If a user hovers over any node, the graph shows information about that word, and how it was used, as shown in figure 6.34 for the word “stretch”. It shows the number of people that used that word, along with how it was used in a phrase, giving the user a sense of context in using that word. Redundant or repeated phrases are not shown in the phrase list, to provide the user at a glance the different ways people have used that term.

Additionally, clicking on the node shows what kinds of fabrics were described as that term, by changing the view to the search view, and including the term as a desired quality in the include search list.

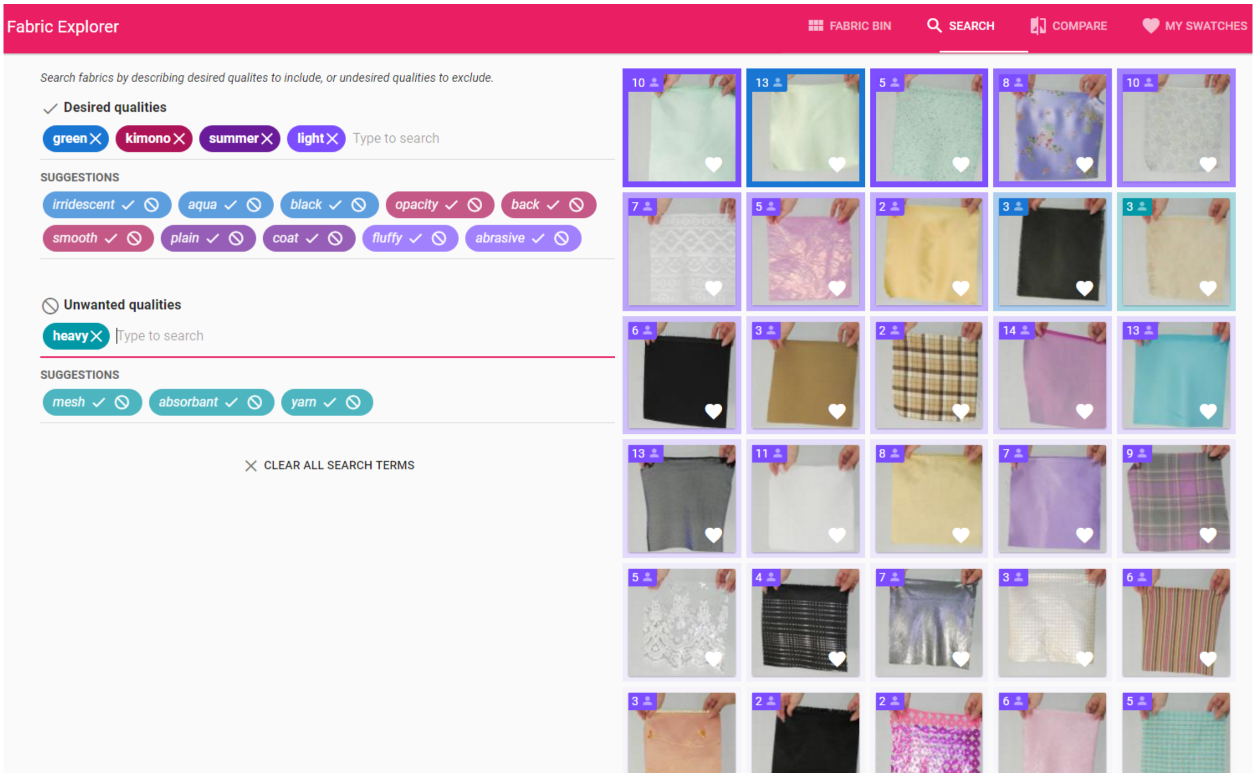


10 out of 22 people used this word
Examples: "low stretch to it
stretch
fairly stretchy
only stretches diagonally
no stretch
stretchy
stretchable
stretchy fabric
somewhat flexible in that it stetches"
Click to find other fabrics described as "stretch"

Figure 6.34: Screenshot of a user hovering over the word “stretch” in the graph of descriptors used to describe fabric in the detailed view. It shows how many people used the word, along with how it was used.

Search

Figure 6.35 shows our search view with many search terms that were desired or unwanted qualities. We describe each feature that this view supports.



Search fabrics by describing desired qualites to include, or undesired qualities to exclude.

Desired qualities

green kimono summer light Type to search

SUGGESTIONS

irridescent aqua black opacity back smooth plain coat fluffy abrasive

Unwanted qualities

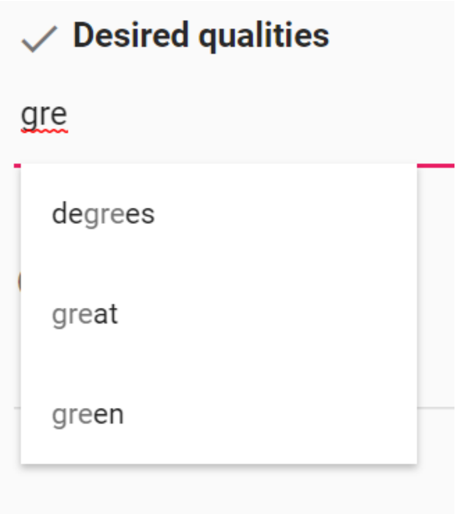
heavy Type to search

SUGGESTIONS

mesh absorbant yarn

Figure 6.35: Screenshot of the search view, where the user is looking for a light, summer, kimono, green fabric, but not looking for a heavy fabric.

Anytime that the user types in a term, it searches against all words used to describe all fabrics, narrowed down to their core word. So if a user is midway typing the word “stretchy”, “stretch” would show up as one of the choices. Figure 6.36 shows this feature while typing the word “green”.



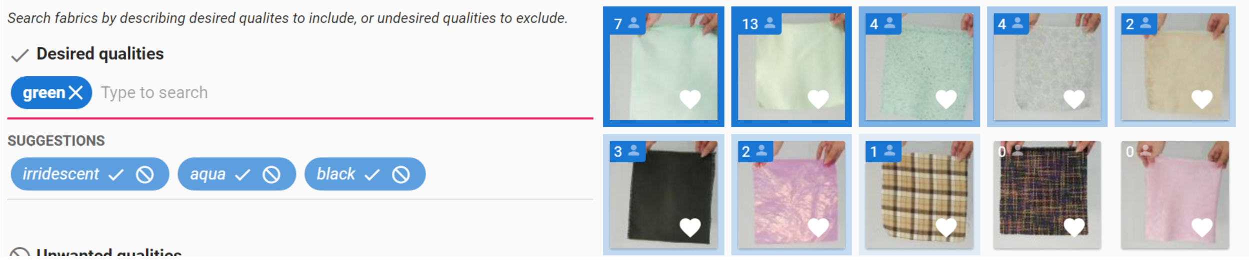
Desired qualities

gre

Figure 6.36: Screenshot of a user typing in the word “green” in the search view, as some term they are looking for. A drop-down list shows all the possible words said before.

The user may type a new word, and the search will keep track of that word. The user may also select an item from the drop down list. Nothing changes when a new word is added in, since the system has no idea on new terms. While the system may not have any information on a term it has never seen before, the system will record the new term, since it may be useful for users if they are unable to find what they’re looking for, and want to be prepared to search in fabric stores elsewhere.

Each search term is assigned to a color, and the same color is present in the suggestions section and in the fabric list, as shown in blue in figure 6.37.



Search fabrics by describing desired qualites to include, or undesired qualities to exclude.

Desired qualities

green ✕ Type to search

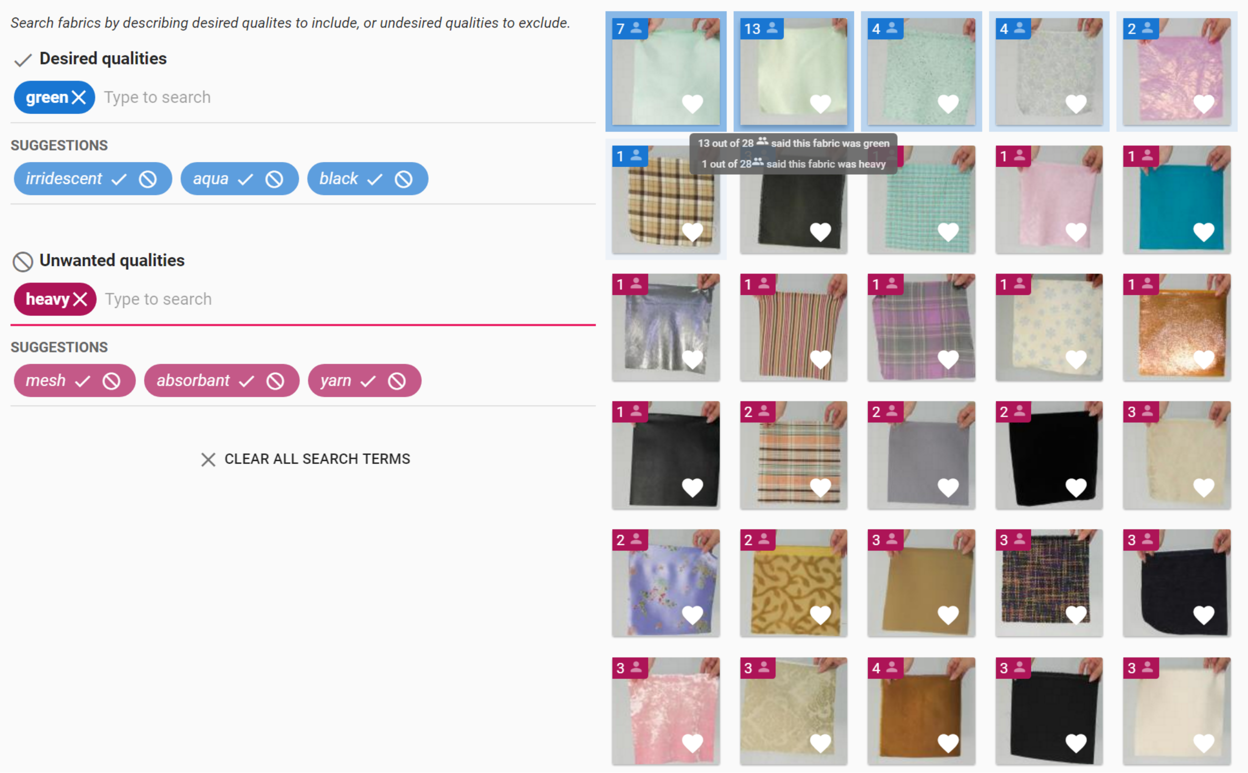
Figure 6.37: Screenshot of the search view with the user interested in green fabrics. The term is colored blue, and left-hand side shows suggestions with the matching color. The right-hand side shows the fabric ordered by how often did people mention the word “green” in the search, with a matching blue border.

Similar colored suggestions imply that the suggestions match to a particular search term. These suggestions are akin to a colleague giving suggestions on qualities to think about. The user can add these terms as desired qualities or undesired qualities, by clicking on the check mark or “no” sign next to the suggestion.

The fabrics list is ordered by how close does it match the search results, according to what people have said. Since different number of people described the fabrics in our studies, the search results are based off of the *percentage* of people using a particular term, instead of a raw quantity.

The fabric has a colored border matching prevalent search term. The border’s opacity changes with respect to the percentage of people using that descriptor, so the user can see at a glance why that fabric popped up in their search results. It also shows how many people used that specific term, and the user can hover over the fabrics to see hoe many people used any of the search terms on the fabric.

To show how this works with a desired and undesired quality, figure 6.38 shows the user looking for a green fabric that is not heavy.



Search fabrics by describing desired qualites to include, or undesired qualities to exclude.

13 out of 28 said this fabric was green
1 out of 28 said this fabric was heavy

Figure 6.38: Screenshot of the search view with a desired and undesired quality. Those fabrics that are described as green are placed on the top, while those fabrics described as heavy are at the bottom. The user hovers over the 2nd top result, and sees that while it was described as green, one person mentioned it was heavy, pulling the result from the top, to the 2nd top result.

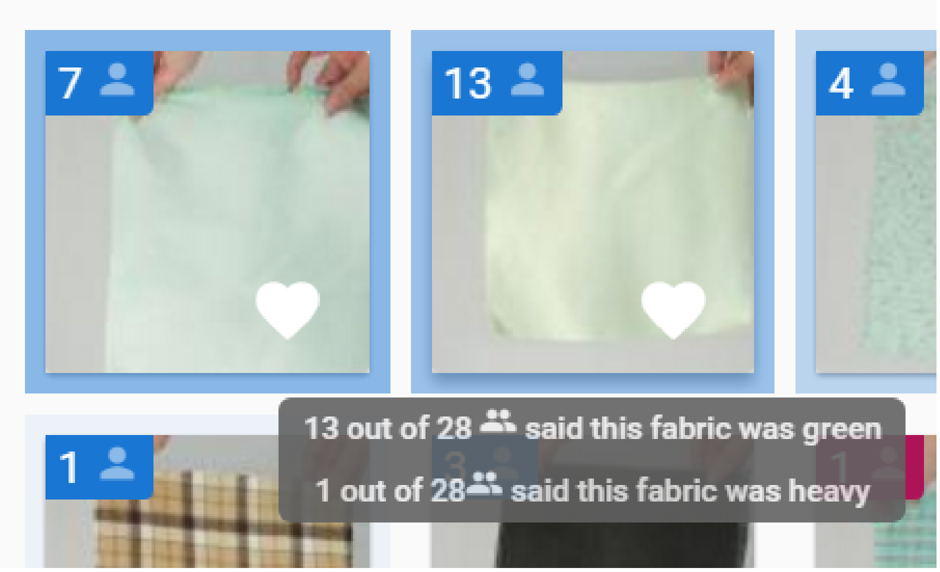
A fabric is closer to the top of the search result if the fabric was described often by the desired qualities, and how often it was mentioned to not have the desired qualities. Fabrics are pushed lower if they are described to have an undesired quality, or mentioned explicitly to not have a desired quality. Fabrics that have no information are pushed to the bottom, because the system has no information on it.

So in figure 6.38, fabrics that were often described as “green”, and/or “not heavy” are pushed to the top, while fabrics described as “heavy” and/or “not green” are pushed to the bottom. “Heavy” fabrics had a magenta border.

The search is weighted based off of the percentage of people that mentioned any any desired quality was mentioned, and undesired with a specific color show that the search term matching the color was the most prevalent quality to the fabric.

Looking closer at the first two search results, figure 6.39 shows a closer view as why a fabric with 7 mentions of “green” is a better match than one with 13 mentions of “green”. The first result has 7 out of 13 people mentioning “green”, and the second result had 13 out of 28 people describe it as “green”. The ordering is based off of the percentage of people using the term, and both fabrics have similar numbers. But, as shown by hovering over the second term, one person described the second fabric as “heavy”, which is a quality the user is not looking for.

Desired qualities and undesired qualities are weighted equally, since our prior studies show that it’s just as important to know what a user is looking for and avoiding.



13 out of 28 said this fabric was green

1 out of 28 said this fabric was heavy

Figure 6.39: Screenshot of the first two search results after finding fabrics that are “green” but not “heavy”. The second result has more mentioned of “green” but, after hovering over the second fabric, because someone described it as “heavy”, it is lower in the search result than the first term.

Compare

Figure 6.40 shows the system's compare view, with two fabrics already selected to compare. After the user selects two fabrics to compare, similarities and differences appear between them. Unique qualities are a kind of difference where a quality was mentioned by one fabric, but not another.

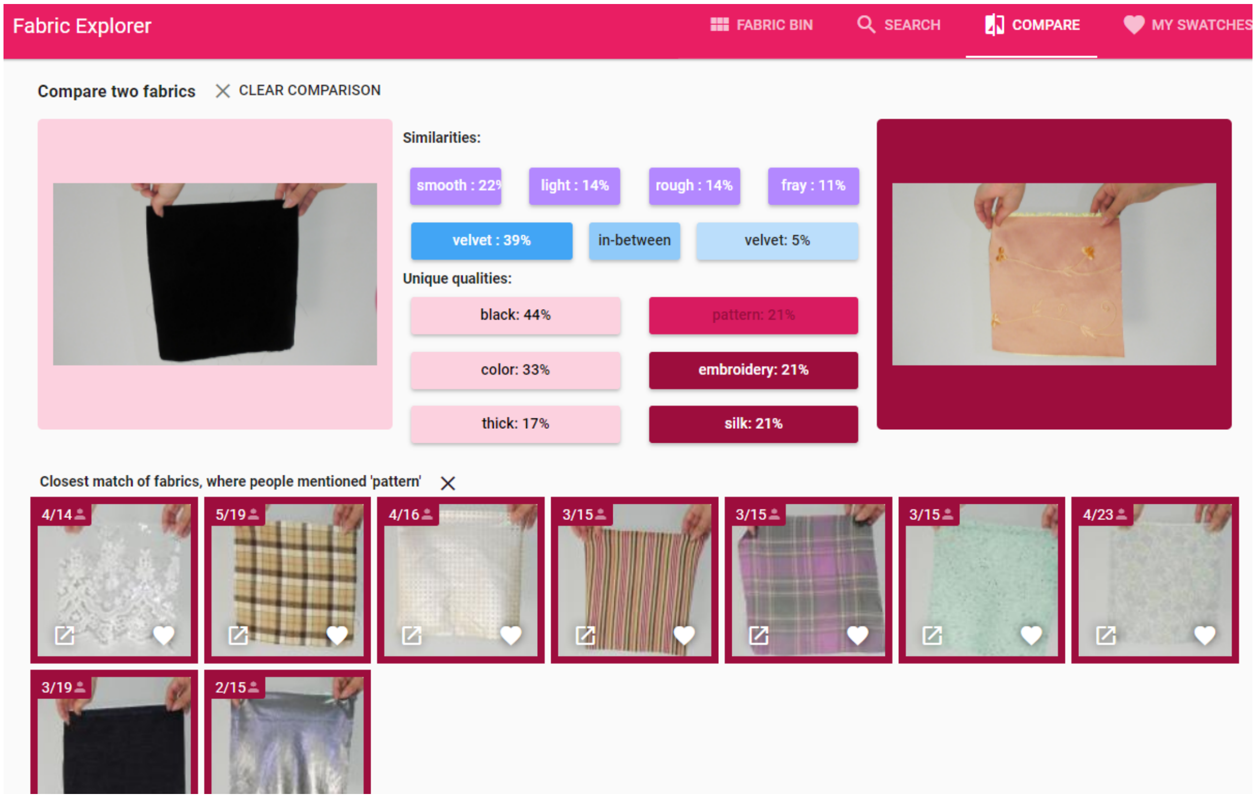


Figure 6.40: Screenshot of the compare interface, with two fabrics selected. The user selected to see fabrics that have been similarly mentioned by its "pattern", shown in the lower third of the screen.

Just like the search results, these comparisons are done by the percentage of people mentioning the term. So qualities that are mentioned by a similar percentage of people, are considered similar. The qualities view are based off of percentages instead of fractions, in order to keep the information brief. The alternative was to present the fractional amount of both fabrics, such as showing "7/14" for one fabric, and "13/26" for another fabric. But, we found that the percentage was enough to see the information at a glance.

Any one of these qualities can be selected, and similar fabrics appear on the lower portion of the screen, with the fabric's border matching the quality's color. In figure 6.40, the user wanted to see other fabrics mentioned by their pattern. Fabrics that have a similar percentage with that quality are shown in the lower-half of the screen, sorted by percentage.

Consistent with the search results, it also shows how many people used that quality.

Since comparing fabrics was going to be what users would do here, clicking on a fabric compares it, differing from usually routing the user to the fabric's detailed view. We provided a button on the lower left-hand side that routes a user to a fabric's detailed view. The two compared fabrics do not appear in the search results to prevent confusion.

The only quality that behaves differently than the others is the "in-between" button. If a user clicks on "in-between" the view shows fabrics that span in between the compared fabrics with respect to a quality. In figure 6.40, if the user wanted to see what else was velvet or velvety between the compared fabrics, the "in-between" button between "velvet"s would provide those fabrics.

Figure 6.41 illustrates what happens when the user looks for something "in-between" these two when it comes to "velvet" or "velvety". This example compared a black velvet fabric with a pink silk with a raised nap in the petals, and both had some mention of the word "velvet" or "velvety".

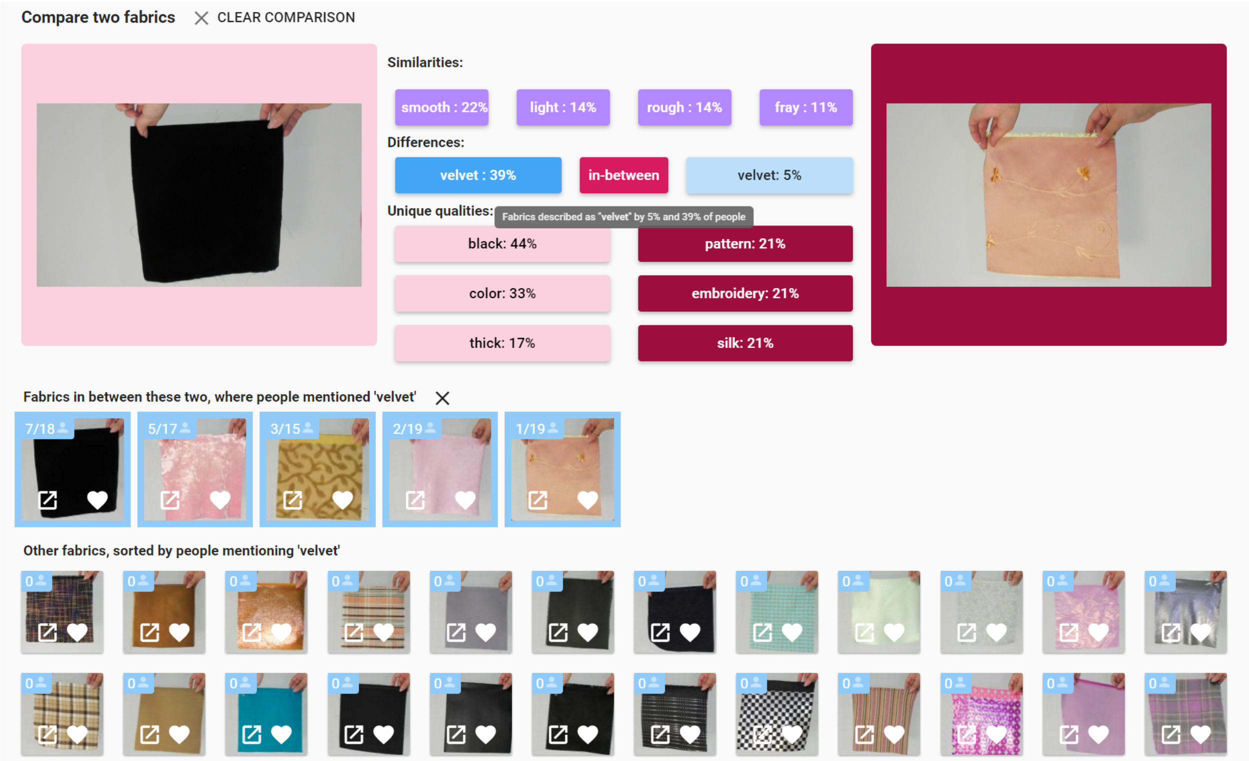


Figure 6.41: Screenshot of the compare interface, seeing fabrics are "in-between" two fabrics with respect to the velvet quality. The user can hover over any quality to see more information, and the user finds that one fabric was mentioned as velvet by 5% of people, while another was 39%. Fabrics that are described in between these two percentages are shown below the qualities, and fabrics that are not in between are still placed in the bottom of the screen, sorted by "velvet".

Below the qualities, the user can see an ordered list of fabrics that are in-between these two fabrics, with these two fabrics forming as book-ends at the top and bottom of the list. The "in-between" selection is the only selection where we see the compared fabrics in the search result, to give the user an added cue on how the relevant fabrics compare to the core two fabrics.

Fabrics that are not "in-between" the core two compared fabrics, are at the bottom of the screen, sorted by the selected quality.

6.3.2 Limitations

The system has some limitations in terms of functionality and how it communicates the materials to users. The first is that communicating **thickness** visually was a challenge, as highlighted in the second crowdsourcing study. If participants described the fabric in terms of thickness, that kind of information would show up in the graph of words.

In terms of study design, we were interested in qualities like thickness would be negotiated between the visuals and the descriptors, so it was acceptable to not tackle that visualization challenge. But, communicating thickness is a system limitation.

Another limitation is trying to deduce how translucent the fabric was. The background was always white, except for the close-up view, so fabrics like the one shown in figure 6.42 may be light in color, or light because of how translucent the fabric is.

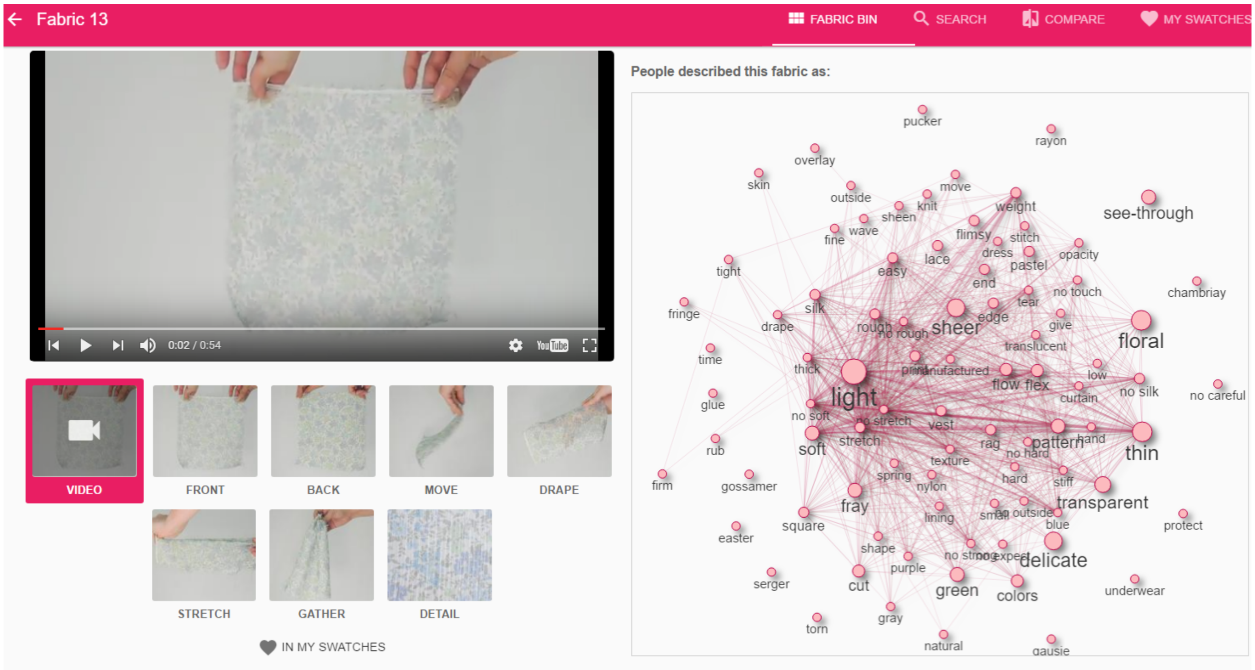


Figure 6.42: The screenshot shows the detailed view for fabric 13, where we illustrate a limitation of the visuals on whether the fabric is white in color, or is translucent.

This limitation is mitigated by the descriptors on the right-hand side, showing words like “light”, “sheer”, “see-through”, and “thin”, along with the close-up view of the fabric in a black background, both showing the fabric is see-through. But this information is not visible in the fabric’s thumbnail view, and gives the impression that the fabric mat be white.

Another limitation with the visuals is a challenge discerning a printed pattern on a fabric, or a nap, or raised area of the fabric. Fabric #40’s detailed view, shown in figure 6.43, may read initially as a printed leaf pattern instead of a textured pattern.

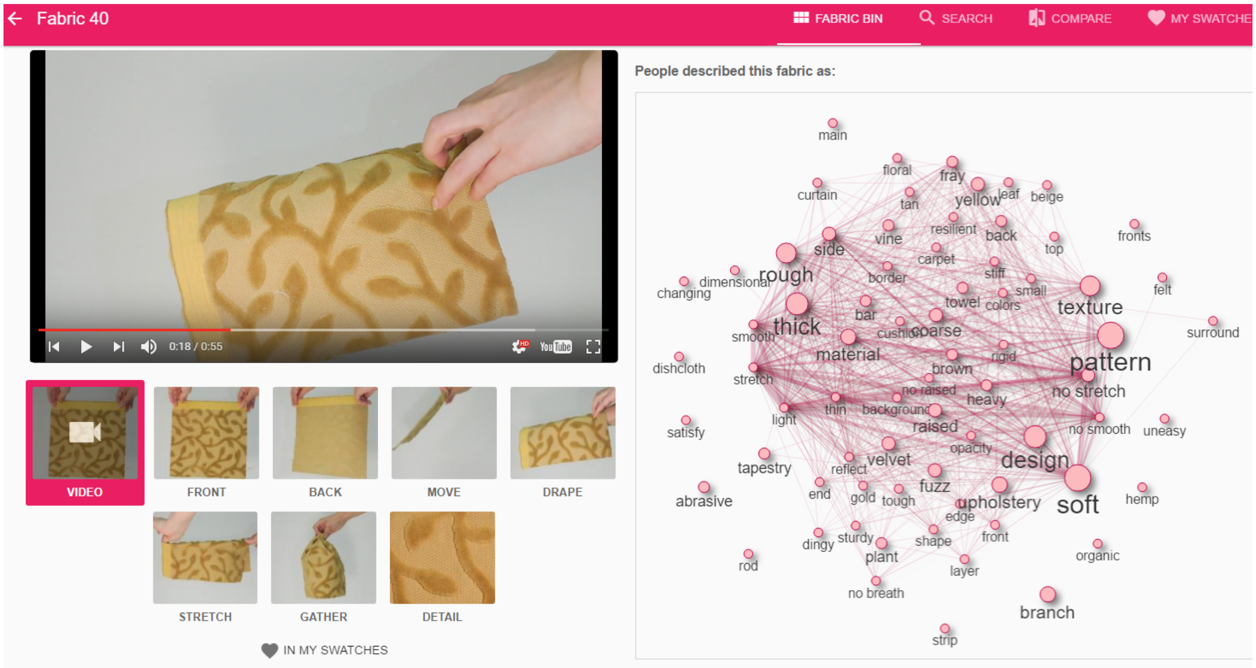
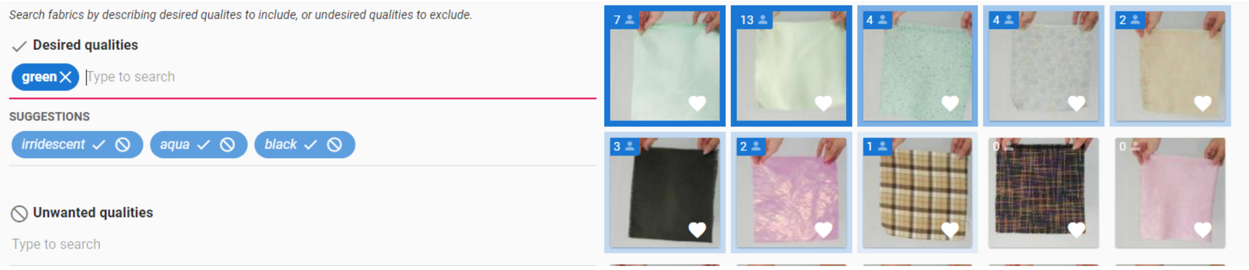


Figure 6.43: The screenshot shows the detailed view for fabric 40, where we illustrate the challenge of illustrating a printed pattern versus a raised texture. The video is scrubbed to where the fabric is draped, but since this point is 18 seconds into the video, users may get an initial impression that the fabric has a printed pattern.

The descriptors were not so clear as in fabric #13. People mentioned "texture", "design" "pattern" were both highlighted, so the descriptors may not immediately dismiss one interpretation over another. The draped image and draped portion of the video reveal raised portions of the fabric. So, while the information is present in the visuals, it may not be immediately apparent to the users, and they may need to negotiate whether that fabric is printed or raised.

6.3.3 Comparisons to Similar Real-World Systems

This system is to study negotiating and making sense of ambiguity, but since it leverages from search UIs, below we compare a few similar kinds of search UIs with our study system. As a quick search, we searched for "green" or "green fabric" on both interfaces as a baseline, and figure 6.44 shows that search result. The search results are sorted by the percentage of people that have mentioned the terms in the include and exclude terms.



Search fabrics by describing desired qualites to include, or undesired qualities to exclude.

Figure 6.44: Screenshot of our system, with searching for “green” as a quality to include.

JoAnns Fabric Store Online

Figure 6.45 is a snapshot of what the user interface is like exploring the site, after selecting search for “green” among their fabrics [2]. On the lefthand side, there are a series of categories to select to help narrow down the results, whether it’s quilting, fleece, utility, design & branda and more. There are also brands that can be selected as well, and not shown are selecting and narrowing down search by color, type (prints, cottons, solids, flannels, etc), design, content, designer collection, and more.

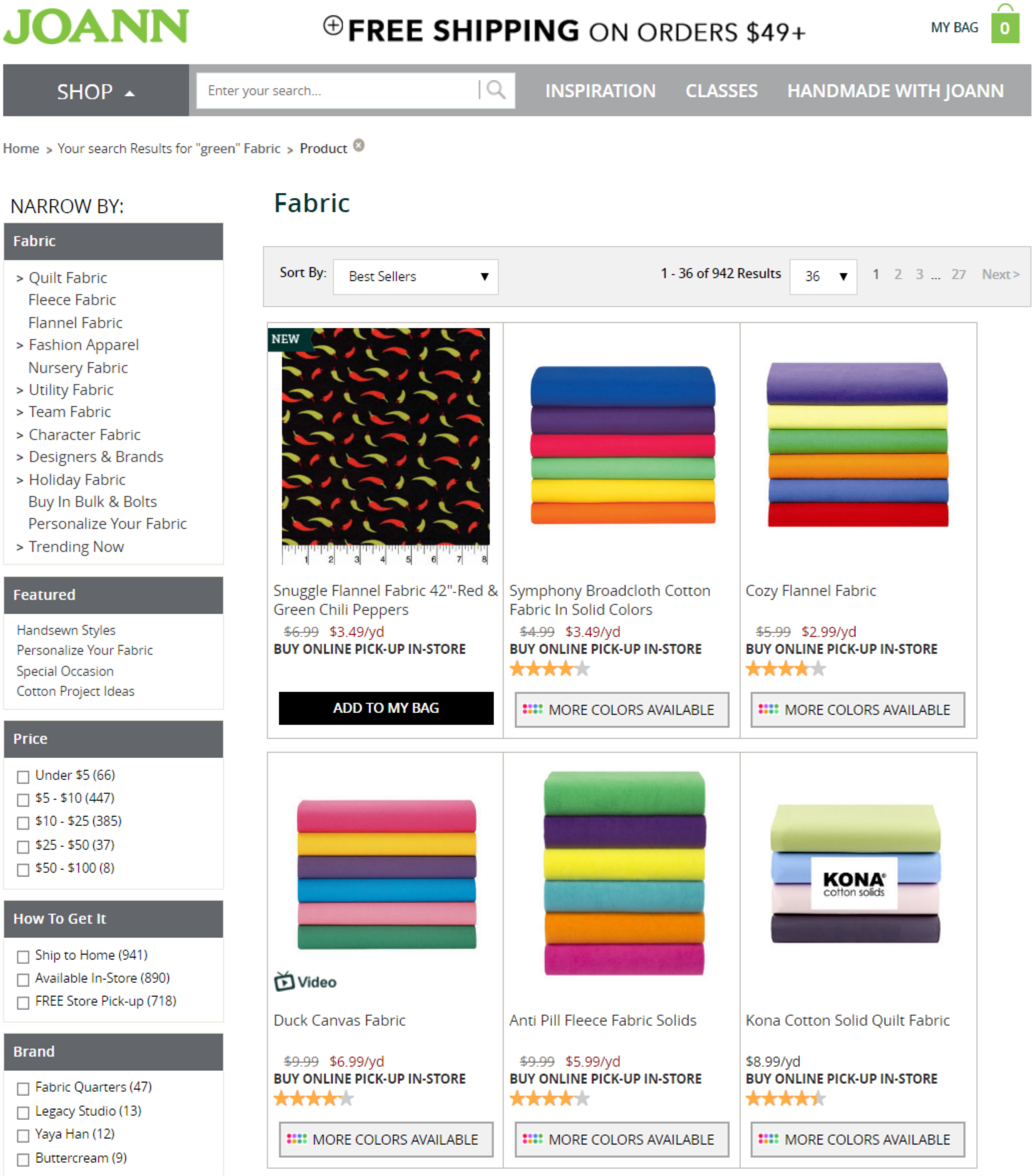


Figure 6.45: Screenshot of the JoAnn fabrics online store, after searching for “green” fabrics.

One of the key differences between the online store and our system is the system's lack of categories anywhere, except in the search view where users can add qualities they want or do not want.

Additionally, JoAnns uses a combinations of descriptors to categorize and classify the fabrics, from professional-grade fabric specifications, labels, and descriptors that have a specific interpretation and context for the JoAnns company.

Since our system is for our study, we did want to add any descriptors that may bias the user, so we only numbers to identify fabrics. In a more commercial setting like JoAnn's store, naming is much more important.

Google Image Search & Filters

The second system that we highlight focuses on Google Image's search and Filters. Figure 6.46 shows a screenshot of the Google images search result for green fabric, with the initial search, the filters of relevant words below the search, and the search results encompassing most of the page.

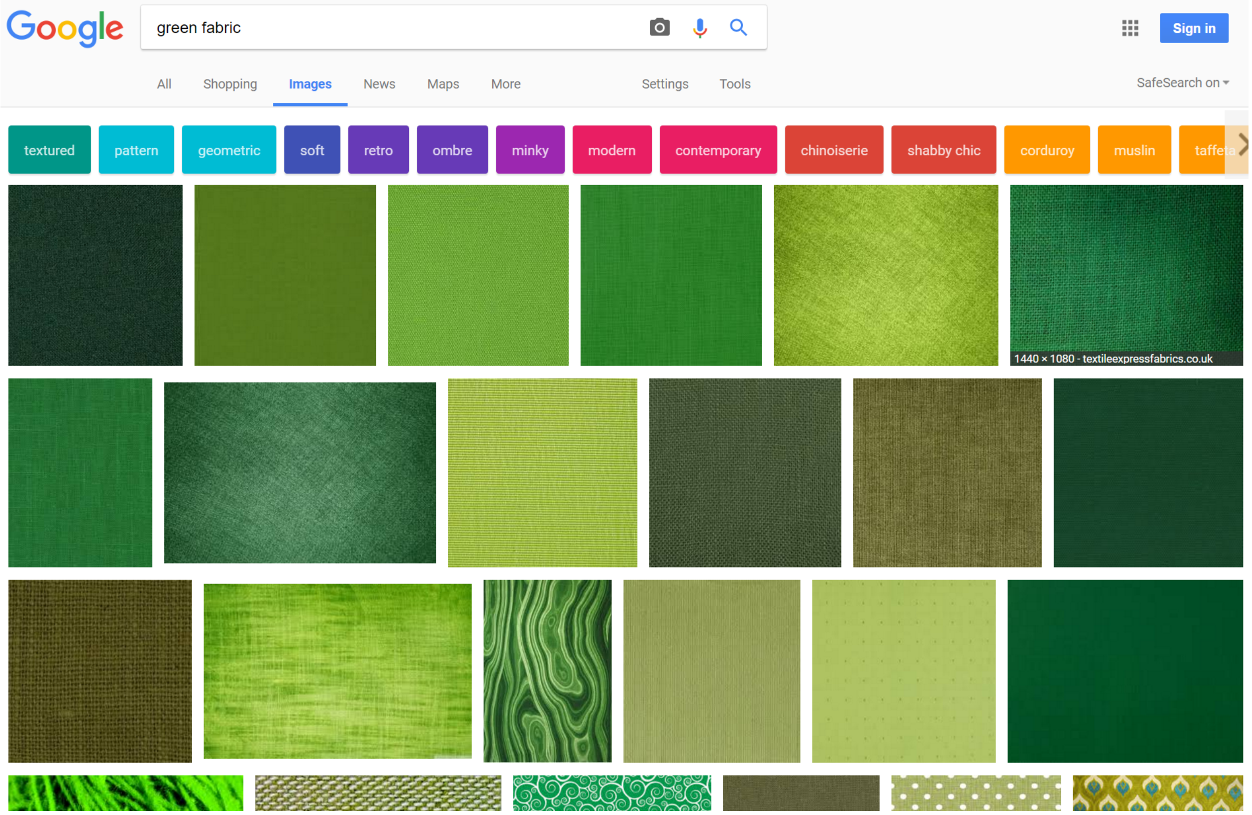


Figure 6.46: Screenshot of Google's Image Search and Filters, for the same query for green fabrics. Below the research result are filters relevant to the query, such as "textured", "pattern", and "retro".

Both Google's Image and our search UI rely on what people have said about the content. Google's search interface nor our system have a notion of what is a fabric or what is "thick". It only relies on what people have said about the material. Both interfaces also show relevant keywords associated with the initial search, and can support terms to exclude. Both also show the close-up view of the fabric, but Google's images may be a result of how fabrics are shown in a commercial setting and not a purposeful design decision by Google.

One key difference is that our search interface expands its results the more search terms it has. For example, if the user selected "iridescent" as something desired, the search results expand, to present the user many alternatives and ideas on their process. Additionally, if the user searches for a new term, our system preserves and presents that result. The new terms may reveal important qualities to the user, and, we imagine that after using our system, the user may take the terms, old and new, and be prepared to search for fabrics elsewhere, online or in live stores. Google's filters, while also are suggested terms, only narrow the results, and not finding a result, even with new terms, is not Google's goal,

Another design difference is that our system is meant for study, and as such, we show the user why certain words pop up, including the term in-context inside a phrase. This information is crucial for the user to try and make sense of and negotiate with the meaning of a word. Google does not reveal nor show why one result is the top result.

Chapter 7

Ambiguity Interfaces Study

After enough descriptors have been collected and the virtual representations have been sufficiently verified, we can evaluate the representations and designs to study how designers understand fabric in this major evaluation study.

7.1 Description Collection

We have descriptors on our original eighteen fabrics from the first crowdsourced study. But we needed more fabrics to have a substantial list for users to explore, to more substantially target RQ3.

7.1.1 Selection of Fabrics

We needed more fabrics diversified our collection. We also wanted fabrics that were either difficult to photograph, or visually very similar to another colors, to encourage participants to explore fabrics beyond a glance.

This time, we collected fabrics from a city fashion district very far away in a different area of the country where we ran the studies. We did this to minimize a study participants' potential prior familiarity with the fabrics.

In searching for diverse fabrics, in addition to collecting fabrics visually similar to what we had, we also asked fabric store owners for fabrics that are unique or are visually difficult to photograph.

Then, we had an expert review of our fabrics for diversity. Our result was 27 fabrics that added diversity to our set, including laser-cut, sequined, iridescent, lacy fabrics. In addition, we have had multiple fabrics of similar color, but vary in other properties, such as black fabrics that vary in fiber content, stretchiness and thickness, along with gold fabrics that have multiple thicknesses and shine.

7.1.2 Survey Design

Given our studies about the limited vocabulary that experts and everyday people use to describe fabric, we asked 17 participants to describe the partial or full 27 fabrics. These participants varied in fabric experience from no experience to professional drafters and drapers. We had a survey that asked participants to describe each fabric, randomly selected.

Since this survey focused on getting information about these fabrics, no analysis was needed, and the same data processing from prior studies were applied on the new data.

7.2 Ambiguity Study

7.2.1 Questions

Our main research question in this study is:

RQ3: How can we *design* interfaces with standard interface toolkits to help designers explore and understand material remotely?

We already studied different visual representations in the prior crowdsourcing studies, but this study focuses on how users make sense of materials through different representations and interactions with materials.

With the system described in chapter 7, this study focused on interactions, or different ways of making sense of fabrics and negotiating ambiguity. Specifically, the detailed view has both visual information (images, video) and descriptions of what people gave (graph of words), so users have an opportunity to use both kinds of information to interpret what that fabric would be like.

This question also incorporate the user's process and how and when they interact with the materials and the ambiguity. The search and compare view also show the individual fabric image as an icon, and uses data from descriptions too, giving opportunities for people to make sense of materials.

7.2.2 Hypotheses

We anticipated that the detailed view is where users would negotiate and try to make sense of fabrics. We expected significant time spent on the detailed view, as users may look at a descriptor, look at the phrases, and look at the video.

We also anticipated that search view would be the most used starting point and the most used interaction in exploring fabrics, since users may think of qualities of fabrics first. We did not see users start by clicking on fabrics in the fabric bin view, nor immediately compare two fabrics.

7.2.3 Study Design

We wanted to be open-minded to different processes and strategies that people would use in such a system. In order to be flexible and capture unexpected processes, we decided to conduct an in-depth exploratory study, with a detailed observation and interview components. In order to study process and focus on negotiation more in-depth, we conducted the study with ten participants, with a longer study so we can inquire and study their process.

Participants

We recruited eight participants who were knowledgeable in a diverse set of fabrics. They were recruited through word-of-mouth, direct emails to potential participants, and emails to crafting lists and theaters, instrcting to pass the info along to their designers or groups. We enforced that participants have any one of the following qualifications:

1. A degree in something relevant to fabrics
2. Has a career relevant to fabrics
3. At least 2 years of coursework relevant to fabrics
4. 10+ years experience in building or designing with fabrics

In order to get a sense of diverse and active experiences with fabrics, we also asked potential participants to share what kinds of items have they built or designed with fabrics, and when was the last time they built or worked with fabrics.

The participants ranged from textile artists, quilters, quilt shop owners, hobbyists ranging with 11-60 years experience, and costume designer. All participants were women, with ages ranging from 24 - 68.

Tasks

The first task was to describe two fabrics before introducing the system and after interacting with the system: one in the system and one not in the system. The fabric included in the system was fabric number 30, the pink laser-cut fabric from the second crowdsourcing study, one of the most uncommon fabrics in the set. The second fabric was a thick upholstery green fabric with lighter and darker stripes.

The second and most important task is to explore the system for a fabric for a future project, or a fabric the user was actively looking for. The fabric to look for could be a specific kind of fabric or could be a vague idea of a fabric or future project.

To help the participants form their ideas for this future fabric, they were given an unlined sheet of paper to describe their fabrics. The paper was mostly for them to brainstorm and did not need to make sense to us. The wording of the instructions was to only brainstorm and to describe the project or fabric. How they described it varied from words to pictures, and we did not want to imply it had to be in an illustration or in words.

Then the participant was asked to share their ideas about the fabric and the project to the moderator. After that, the participant used any part of the system to explore and find a fabric suitable for the task. Participants were instructed to find a fabric/s that what close to what they were looking for, or to inform the moderator when they did not find what they were looking for in the set.

Relevant Equipment

In addition to the software described in Chapter 6, we ran the entire system on a Microsoft Surface Pro 3, using the built-in speakers and microphone. It has Windows 10, 8 GB of RAM, an Intel Core i5-4300U processor, and a 2160 x 1440 LCD 10.8" display.

Study Tools

Pre-questionnaires helped us collect participants' prior experiences. Part of the pre-questionnaire information was captured in the **pre-screen questionnaire**, used to assess if a potential participant had enough experience with diverse fabrics to quality for the study. The pre-screening asked participants their education level, degrees, coursework, professional experiences and general hobbyist experiences relevant to fabric. If they qualified, the pre-questionnaire asked demographics questions, along with how they explore fabrics.

Additionally, since we are introducing a new technology, we used a measure for **technostress** and **computer self-efficacy**. We wanted to measure technostress, or feeling overwhelmed when a new technology is introduced to a process, and computer self-efficacy, or one's capability and confidence in computers, because our system is a new technology to be introduced as part of a user's process in exploring materials. In a sense, a user may perceive the system as a hindrance getting in between them and feeling the material directly. To detect such sentiments, whether due to stress or lack of confidence in technology, we employed Tarafdar's technostress measure [58] and Compeau's computer self-efficacy measure [12], both validated with one another through other studies [54].

Since this system relies on making sense of another's description, we also used a creativity and divergent thinking measure. That is, if a user is not very willing to see another's point of view or different ways of thinking, they may not place value in what others have said about the material. While looking at different measures, one reliability study measured different kinds of creativity and divergent thinking measures, with the conclusion that if the inquiry was domain-focused, to use a measure that is sensitive to domains [65]. One of the validated measures was Kaufman's Creativity Domain Questionnaire-Revised(CDQ-R), revised and validated from an older measure. This measure focuses on measuring creativity with respect to different domains [29], and since this study focused on art, craft, and design, this measure was the most suitable for the study.

We used a **web site analytics tracker** to track **navigation paths and durations on each view** in order to better understand a **user's exploration process and attention**. Since we are using an out-of-the-shelf web tracker, we could extract information like speed, as it may be significant to see how efficiently designers find a desired fabric. However, we anticipate that such a metric would not be as important, since this study focuses on process and negotiation.

Given the importance of process, we also recorded **audio and video** on the website as users explored the site, as a redundant measure.

In order to capture how the user **negotiated unclear or contradictory information on the site**, we asked participants to speak aloud and inform the moderator when they found initially unclear or contradictory information. The observer would record the instance, and observe **the user's actions**, capturing the **fabrics involved**, the **information** that was unclear, the **page view** in question, and **navigation paths** that occurred after that point, assuming it was to negotiate with the information. The moderator would then inquire and verify the user's process in a later interview.

We also studied **differences in describing fabric** by measuring the quantity and quality of describing two fabrics before and after the main study task.

A **semi-structured interview** helped wrap up all the experiences and get overall trends, questions that came up in the pre-questionnaires and observations, along with the user's impressions. The interview asked participants about their thoughts on the system, how they communicate a desired fabric in real-life, how they used different parts of the system, and some clarification questions from the post-questionnaire and the observations

Procedure

The study location was in public areas and office spaces where wifi and power were available. Since experienced builders and designers were limited in the area, we designed the study to be flexible and able to be run in public areas like coffee shops, where we could go to participants and conduct the study.

First, the participants filled out a pre-screening questionnaire online. If they qualify, they filled out the pre-questionnaire online before meeting for the study itself.

Then, once the moderator met with the participant, the participant described two fabrics. After that, the moderator introduced the participant the system in pieces (bin, detail & swatches, search, compare). At the end of going over a piece of the system, the moderator asked the participant to think of a fabric they worked with recently, and explore the fabric with those pieces of the system reviewed.

After all the parts of the system were introduced, the moderator asked the participant whether they are looking for a fabric for a project, whether it's an exact fabric, an idea of a fabric for a project not yet formed, and everything in between. Once the participant settled on a fabric to search for, the participant brainstormed ideas on a large unlined seethe of paper and pencil. We provided the unlined paper and asked participants to brainstorm to not bias the participant to communicate in terms of text or sketches. The brainstorming session was for them to jot down some ideas on paper.

Then, they were asked to talk about the fabric and project. After that, participants used the entire system to explore, looking for fabrics that may match what they're looking for. Participants were instructed to speak up whenever they encountered something that was unclear, confusing, or ambiguous. The participant stopped when either they found fabric(s) that were what they were looking for, or found nothing. Then they completed the pre-questionnaire and afterwards, the moderator conducted a semi-structured interview.

7.2.4 Results

We present the results relevant to process, exploration and negotiating strategies with respect to each view in the system.

Task Results

Table 7.1 shows a brief summary of how the task went for each participant, identified by participant number. Participants were supposed to stop when either they found fabric(s) that met their criteria, or not, but few did not do this, and changed their projects and their sought fabric multiple times, both for exploring the fabrics and for finding a project that the 45 fabrics could be used for. While those results were obtained out of protocol, those participants still explored materials using the system.

Partic-pant #	Background	Searching For	Found?
2900	Hobbyist: 50 yrs.	sturdy tight weave, cotton or blend, medium weight, turquoise/green tones	yes
8415	Costume/Fashion Designer	want to separate the various colors of fabric into consistent geometric pieces to be reconstructed as separate solid pieces	yes, but switched projects mid-task
2134	Textile Artist	cantaloupe colored, print texture, 100% cotton, mid-weight, woven	yes, but switched projects mid-task
9125	Engineer-Hobbyist: 11 yrs.	cotton, soft, woven, lightweight, good drape, girly, not floral, breathable	no
9108	Quilt Shop Owner	green, or autumn tone leaves on pale blue background, 100% cotton batik,	no
1002	Hobbyist: 60 yrs.	Beautiful, cotton as well as with shine, sparkle or unique threads in blue, purple, magenta. Lots of words and phrases both built into the fabric as well as embroidered on.	no
7494	Hobbyist: 50 yrs.	light weight, silk, black, batik lining, for a young 31 year old woman, preshrunk, wrinkle resistant	no
7079	Masters Textile Science	coarse, durable, able to be punctured multiple times, not stretchy, not shiny, large pattern, one sided is ok, bright colors	yes

Table 7.1: Table showing a summary of how the task went for the participants, showing a brief summary of their backgrounds, what they were looking for, and what happened in the task.

Unclear or Negotiation points

Table 7.2 shows a list of points where participants reported to have needed to negotiate the meaning of fabric because some aspect was unclear or ambiguous. This information was obtained either self-reported while interacting with the system, while asked in the post-questionnaire, or through moderator's observations.

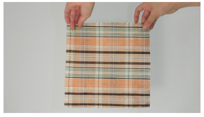
#	Background	Unclear-Negotiation Points
2900	Hobbyist: 50 yrs.	Cotton versus silk fabric. Search showed fabric # 7as a cotton, but descriptors showed it was silk. Was not sure if it was a cotton-silk blend. Determined it was silk. 
8415	Costume/Fashion Designer	1. Negotiated between a print or a textured fabric, fabric #40. The design appeared to be a print, but resolved to a texture due to the angle of the video where the nap was visible.  2. Saw the word “weird” was used to describe fabrics in the search list. Clicked on it, clicked on a relevant fabric's detailed view, deemed that it was not weird.
2134	Textile Artist	Used search view for “silk”. Clicked on fabric #41's detailed view and, exclaimed "Oh, that's probably raw silk".*Moderator's note: No raw silks are in the collection.* 
9125	Engineer-Hobbyist: 11 yrs.	“Some of the descriptors to do with weight were very vague "heavy" vs. "light" is pretty relative.”
9108	Quilt Shop Owner	None mentioned
1002	Hobbyist: 60 yrs.	None mentioned
7494	Hobbyist: 50 yrs.	None mentioned
7079	Masters Textile Science	None mentioned

Table 7.2: Table showing a summary of points in the study where participants felt some aspect was unclear, confusing or ambiguous.

Negotiating Meaning of Fabrics: Process

Some participants relied on both the video and the graph of words to get a better sense of the fabrics. One participant had a small list of fabrics and looked at the detailed view of some of the fabrics. They compared the movement and look of the fabric to what the graph of words said, to deduce that the fabric was a pleather, by the look of the fabric and the mention of pleather in the graph.

While search view was often used, other parts of the interface also supported participants' process in negotiating meaning. One participant, #7494, used the compare view to compare a series of six fabrics by first marking fabrics of interest with the heart button, then comparing each two at a time to see if they were close to what they were looking for. Another participant used the compare view to compare one fabric of interest, to another not of interest, to see if they shared undesired similarities.

Other participants were wary of what other people said about the fabrics. One participant, #1002, searched for a "knit" and saw one of the fabrics that they held in the earlier part of the study, did not come up in the search results. The participant said that because this fabric is stretchy in different dimensions, the fabric must be stretchy. Neither fabric in the earlier description task of the study were knits.

Additionally, the participant also was skeptical of other fabrics that were labeled as "knit". Fabric #37 was described as a knit by others, but the participant noted that because it was stretchy in one dimension (the bias, or diagonal of the fabric), that it could not have been a knit.

Another example was when participant #2900 wanted cottons explicitly and typed in "cotton" in the search. Some fabrics were described few times as cottons, but were also labeled as "silks". That participant communicated frustration that they simply wanted cottons and nothing else. That participant saw some fabrics that were described as "cotton", but relied solely on the video to deduce whether the fabric was a cotton. Another participant, #2134 determined the fabric as a raw silk directly from the video and dismissed the graph because "cotton" was included. There are no raw silks in the dataset, however.

Another example of participants valuing what they see first is when one participant was looking at an image of a mesh white fabric in the compare view, and 50 percent of people described the fabric as white. The participant was unsure whether 50 percent white meant that half of the fabric was white. The moderator informed the participant that it meant that 50 percent of people used the word white to describe the fabric. The participant retorted about how could someone not describe the fabric as white.

Few exclaimed to be hostile towards the negotiation process and wanted to look at specification and the visuals of the fabric. Participant #2134 asked but "what if a moron answers this question?" and described the fabric. This participant also quoted a TV show and noted that they wanted "just the facts, ma'am", and wanted to see how the fabric behaved on video. Another participant, #9125, wanted "normal quantitative things that you would know about the fabric. But [the system] does not stand alone very well since people are not reliable sources for actual data".

Fabric Descriptions

Table 7.3 highlights a summary of how participants used different views and different parts of the system to explore fabrics. The raw pre- and post- study can be found in the appendix, but to summarize the data, it shows the differences, if any, between the two fabrics overall, and the participant's response as to why the changes occurred.

Seven out of eight participants used more descriptors after interacting with the system than before the study task. When asked, five participants attributed the added adjectives as ones they saw in the interface.

The last participant, #7079, mentioned that initially their descriptors were broad. But after interacting with the system, they thought about giving someone a good point of reference for the fabric. They reflected that in her experiences in making sense of fabric remotely such as shopping online, they usually know the fabric already, and are confident in what they order.

#	Background	Differences	Reasoning
2900	Hobbyist: 50 yrs.	Added: Heavy, woven	Saw words in search view and graph
8415	Costume/Fashion Designer	Added: textured, lightweight, easily manipulated, heavy, upholstery weight, light stretch on bias, two sided	“I did not want to reuse the same words.”
2134	Textile Artist	Added: shiny, two-sided, green with beige/gold,lighter on back side, off-set grid design, slight shine to some threads	“no idea”
9125	Engineer-Hobbyist: 11 yrs.	Added: geometric, heavier, different warp	“It came up when seeing the words of what other people came p with. It gave me more ideas.”
9108	Quilt Shop Owner	Added: sided, drapey, tightly woven	“Having looked at other descriptions, it made sense to me to add more information.”
1002	Hobbyist: 60 yrs.	No differences	
7494	Hobbyist: 50 yrs.	Removed: dance, Added: Weight	“It was just things that I thought of, after seeing the descriptors. If I can go back, I want to redo them again.”
7079	Masters Textile Science	Added: holey, glittery, pink, sided, no weight, color, fuurniture, upholstery, sided	“(During) the first time,... the descriptors are not very specific and are very broad, but going through this, there was a lot more specific descriptors and it was more of really thinking about someone who might not get to see this fabric, but they would really want to know about it. With JoAnns.com it’s for a fabric I saw in the store and already know what that fabric is, versus having no reference point for a lot of these fabric. ”

Table 7.3: Table showing how two fabrics were described before and after the main study task. If there were any differences, participants were asked why, and the last column are their responses.

Per View

The *Fabric Bin View* was a first start for two participants. In particular when the participant was looking for a specific color or pattern, the participant can glance and see what's available. Participant #2134 wanted watermelon-printed fabrics, at a glance, could not find anything. Participant #9108 wanted a batik fabric, or a fabric with a distinct dye style, and saw in this view that we did not have any fabric that had that pattern.

The *Detailed View* was heavily used by all participants. In particular, all participants found the video especially useful. One participant noted that the video did want they would have done with the fabrics. Several participants liked comparing the video with the graph of words to make sense of the fabrics. One participant mentioned that the image thumbnails were big enough to be useful. All participants hovered over the graph of words.

The *Search View* was the most common first start for six participants. One participant expected the search result to narrow down results as they added keywords. But since the search expands the search results, the participant was not satisfied with the results. Another participant explicitly liked the search results expansion, noting that as a quilt shop owner, when customers asked for recommendations for fabrics, they would include different and unexpected fabrics in the selection, to spark new ideas.

The *Compare View* was used by four participants, and there were two pervading strategies. One strategy was the using compare to compare two fabrics that were the right color, but wanted to see the similarities and differences. Another strategy was to understand one fabric better by comparing it with a known and understood fabric. One participant had a compelling fabric, but the participant couldn't determine how stretchy the fabric was. There was a fabric that the participant identified as stretchy, so she used compared a fabric of interest with a stretchy fabric to see how much did an undesired quality show up.

The *Swatches View* was used by only one participant, but it was used to mark fabrics of interest. The participant used it to initially mark all black fabrics, and to keep track of whether these fabrics had a suitable fiber content for her project.

Fabric Exploration Process

Below outlines a summary of what participants did during the study process. For detailed raw navigation logs, please see section E.2 in the appendix.

Participants that looked for specific fiber content, color or a specific category of fabric were not successful in finding their desired fabric. For example, participants searched for "cotton", a bright red, "batik", a specialty print popular in quilting cottons, and they quickly found limited or no results using search or fabric bin.

Other participants changed their queries as they explored their task. For example, one participant wanted fabric for a tunic for her daughter. Initially she wanted something made of cotton, but expanded her search to other fabrics that would also be suitable, and narrowed the search with qualities she did not want, such as no stretch.

Two participants quickly did not find what they were looking for, and proceeded to do other search queries for other projects there were looking for, without informing the moderator. Thus, it was hard to tell which part of the exploration were for one project, and which were for another project that the participant did not share with the moderator.

Some participants noted that there weren't enough fabrics in the list, particularly with participants looking for cottons and categories of cottons. Participants that were quilters often searched for cottons, a common fabric in functional quilts, and were not able to find enough. Those participants wanted expert fabric users to describe the fabrics with some set of standards. Participants that did not have a precise desired fabric were ones that used most views of the system.

7.2.5 Discussion

There was some confusion in representing what people said about fabrics. The 50 % white fabric example was meant to convey that 50% of people labeled the fabric as white. Yet, the user interpreted it that the fabric was half white.

One of the design questions that arose from this study was: *what do people do when they do not get what they're looking for?*. Some participants changed what they were looking for, while others stopped entirely. The system was meant to be a part of a dialogue to help the user explore what they could use. If the system were a person the user was chatting with, and the user did not find what they were looking for, what would the system say?

Influence of craft domains

In terms of collaboration, we wondered if your environment influenced what you valued. Some participants that did not understand the graph of words nor the search results were quilters, and if the quilter were making a functional quilt, fabric choices are severely limited to cottons and other natural fibers. Given our choices in maintaining diverse fabrics, we did not have many choices in quilting cottons, so those participants quickly found that the system did not have what they were looking for. Users crafting with particular kinds of design constraints and guidelines, like those for making a functional quilt, may not find such design systems to be useful to them.

Some of our participants were also hobbyists, so those hobbyists may have not had a need to negotiate with someone else's interpretation of materials. If the hobbyist were shopping in a store, like what our quilt owner participant shared, employees are meant to give suggestions and choices to customers, not necessarily to share the employee's specific interpretation of a fabric. If the hobbyist works by themselves, their own interpretations are the ones they value the most.

In contrast, other design domains require heavy collaboration with others, which already support negotiating the meaning of fabrics. For example, in costume design, a designer supports the vision of a director for a production, and must produce and communicate designs that convey that vision. A designer may also collaborate with a cutter, drafter, stitcher, and draper, to help negotiate how a fabric may read on stage.

Design domains that require collaboration may be used to negotiating meaning, and our system would better serve those domains rather than ones with guidelines and constraints.

What does knit mean?

There are multiple instances where participants relied on what they valued what they saw more than what others said about the fabric. In the prior "knit" example, the participant dismissed what people mentioned ("cotton", "silk"), and asserted the fabric is a knit. The fabric was actually not a knit. Another participant asserted that one fabric was a raw silk when it was not.

Both of these participants desired expert review with standard ways to describe fabrics as well, The definitions of raw silk and knits are precise. Yet, those definitions were not applied in this situation. It's likely that these participants thought of properties that were common in knits, like stretchiness, and associated stretch with knits.

In exploration situations, do users really want a knit fabric, woven like a knit, or do they want something that reminds them like a knit, with its stretchy property, for example?

The system provided suggestions based on what people said about the fabric, which has a limited vocabulary. From that, the system helps, but does not resolve the ambiguity. In particular, the descriptors from people do not collectively form a complete picture of the fabric.

Chapter 8

Implications for Design & Design Guidelines

8.1 Implications for Design

From our findings, our implications for design are the following:

8.1.1 Nature of Description

While we did not explicitly study what makes a useful description, these studies have given us some glimpses in that piece. Users were able to make sense of words that they used themselves, which both helped and hindered understanding, highlighted in section 8.1.2.

The next glimpse was between the word and the phrase level of these descriptions. Our work initially delved into the word level for text analysis, and later in the last study, used words as a handle for phrase-level description. If users did not agree with or understand why a particular word was present, users had access to the visual representations or the phrase level, that helped make the individual word easier to understand.

Below are two kinds of words, negation of a descriptor, such as "not wrinkly", and a property, like "texture", both counted as descriptions, even though they may not be thought of as a descriptor by themselves.

Since we asked participants to describe salient qualities, including property-specific information and negations meant including more information about the fabric. For example, if someone noticed that the fabric did not wrinkle, or had a unique texture, these comments were informative to the fabric. In our system, both of these descriptors would be shown as "no wrinkle" and "texture", respectively.

We include reasons to use it or not use in design, and how their inclusion helped or hindered understanding.

The Usefulness of Properties as Descriptors

Fabric properties were actively included in the system, though such properties may not be good descriptors. In practice when doing the text analysis, we wanted “stretchy”, “some stretchiness” and “has some stretch” to resolve to the root word, “stretch”. “Stretch” by itself is not a descriptor, since it could be used that it had no stretch or very stretchy. “Stretch” is usually thought of as a scalar descriptor, paired with words like “no stretch”, “some stretch” or “very stretchy”.

Some examples led to more confusion than others. “Texture” and “side” were terms that did not describe the fabric by themselves. That is, all fabrics have some sort of texture and have two sides to them, so these words did not reveal anything about the fabrics. “Side” also could not be thought up in scalars as well. “Very side” makes little sense.

These words were more clear once users saw the associated phrase level, seeing phrases like “like the texture”, “light sheen and texture”, and “both sides are fairly rough”, and those phrases give better insight on how the fabric behaves and how it can be used. For example, fabrics that are not the same on both sides may restrict how it can be used in quick change or reversible clothing.

In terms of design, designers have the choice between excluding them or including them. Including properties may lead to interface and representation implications, whether treating properties just like descriptors, or represent them differently.

It depends on how those words were obtained, and the property’s association with other words. If the words were obtained through a structured inquiry, like asking to describe the fabric with respect to “texture”, then properties like “texture” may need to be visualized differently than other words, or removed all together as a descriptor, and made as a category, where similar “rough textured” materials may be grouped together.

Negative Descriptions

Negative descriptors like “no stretch” or “not stretchy” seem self-explanatory, and they make sense because the absence of a property is reasonable. With this logic, our system preserved all negations.

But, some negations, such as ones that pair a negation to an adjective or some nouns, such as “not silky”, are not as self-explanatory. Our inquiry focused on salient properties, so if someone described the material as “not silky”, then it may be reasonable that this fabric is the antithesis of silky, such as the descriptor “very not silk” in our dataset.

But, it also raises more questions. Some material that is not silky can also not be linen, not cotton, or not plastic, among many other possibilities. Negation describes what the material is not, not necessarily what the material is. Why did someone say “not silky”, out of all the things that a material may not be?

One of the insights from our dataset is some descriptions talk about deception, in that some materials may read one way, but have a deceptive quality that is not determined at a first glance. Our “not silky” example also applied to the descriptor: “looks like silk but it’s not silk”. One example of “no color” came from “discoloration from scratches or folds in the fabric”, implying that some of the colors there may have been there unintentionally.

Another use of negation is to share recommendations on how to not use the material. The phrase “no dress” described how one user would “not make a dress out of this”.

Whether presenting negation paired with a property or with an adjective, negation presents interface and representation issues for designers. Contradictions in description, such as showing that the fabric had both “no stretch” and “stretch”, along with general collective uncertainty are both covered in depth in later sections 8.1.4 and the immediate following section 8.1.2. But, negations by themselves, without contradictions, may merit a different visualization than other descriptions, since negations imply how not to use the material, some deceptive quality, or even the lack of some quality.

8.1.2 Collective Uncertainty in Description

Focusing on RQ1 & RQ2 that seeks the properties and ambiguities relevant to description, the ambiguities involved in this domain appear because of various factors.

The first factor is a confusion between a quality category. In revisiting the “cotton” versus “silk” negotiation, the participant tried to negotiate whether the fabric was a cotton or a silk. The participant did not initially think that someone could describe the fabric as “silky cotton”. Initially, “cotton” and “silk” were categories, and description alone does not make it apparent whether the description is meant to be a quality or a category.

The second factor is relevant to differences in perception. Someone’s “heavy” may be someone else’s “thick”, exactly like the earlier examples in the introduction. Even two people using the word “thick” may be describing different things. There are complex associations with these descriptors that are non-trivial to deduce the meaning behind words.

The are also a limited and reused vocabulary in describing materials like fabrics, with few distinctions between practitioners and everyday participants. While the limited vocabulary may imply that there is an understood and shared common language, in our studies, one word may have multiple interpretations, even ones with a practitioner-focused definitions like “knit”.

Finally, we saw examples of practitioners applying their experiences to provide domain-specific languages and understandings. For example, costume designers used terms to describe characters. Surprisingly, while we saw examples, we did not find conclusive data on domain-specific kinds of descriptors or uses of data between the different domains of design and craft.

8.1.3 Collective versus Individual Understanding

There are different ways to make sense of this ambiguity, and especially in our prior study, we found users rely on, negotiate, or solely use one or two different kinds of understandings. With different kinds of understandings and negotiations, we address RQ3.

The first kind of understanding is from the collective. This system employed a “family-feud” style of showing consensus, referring to a game show where contestants answer questions based on what a group of people answered. Initially, even while designing this system, we imagined that predominant qualities would be used often and have a large amount of consensus, in the 80%-90% range. But because of different words potentially having the same meaning, we saw consensus in our system reaching 40% of interpretations.

Additionally, because of the multiple interpretations one word could have, the 40% consensus may be more disparate than what initially seems. The sum of these descriptors also may not combine to form the fabric itself. “Silky cotton” does not imply that the fabric has any silk composition.

Individual’s Understanding

The second kind is an individual’s understanding, and an individual’s understanding came in multiple forms. The first form is the lone or less used descriptors that may give the user enough insight to either understand the material better, or to give the user more ideas on what they are or are not looking for. If one person described a fabric as one for a “pharaoh”, that lone word by one person may illuminate a user to how that fabric can be used and read as.

The second form of an individual’s understanding is the user relying on what they see and feel instead of the collective understanding. We say this predominantly with the ever popular video of fabrics. Select participants ignored the collective understanding and focused on seeing the visual representations to make sense of the fabrics.

The last form is an individual’s understanding with their interpretation concrete, established categories, and/or with quantitative, measured information about the fabric, such as fiber content percentage. A user may apply prior knowledge to what 100% cotton feels and behaves, and apply that understanding to other fabrics with similar kinds of information.

8.1.4 Misrepresenting Uncertainty

Because of the nature of ambiguity in this domain, misrepresenting the uncertainty is a challenge, and the challenge occurs in many levels in computing.

Processing Uncertainty

Designers must be cautious of how the ambiguity is represented and processed, since it may be quite easy to misconstrue or misrepresent the ambiguity.

Our data processing performed a very simple machine learning algorithm: pattern matching. That is, words that have the same base, were considered to be the same. It's difficult to tease at the meanings between different words like "dark" and "black", and it is also equally as difficult for pattern matching to deduce whether two people using the same word, meant it in the same way. Just like "knit" is subject to multiple interpretations, so is "light", whether in color, weight or transparency, among others.

Pattern recognition, as an example, relies on a shared language, which does not apply to this kind of uncertainty.

Visualizing and Interacting with Uncertainty

The challenge of visualizing and interacting with uncertainty comes from the nature of consensus. People agreeing on a term does not imply the negation of a term's inverse. That is, if 40% of participants described the fabric as "stretchy", it does not imply that 60% of participants disagree, or that there is no possibility that it may not be stretchy.

In fact, to illustrate opposites, if 20% of participants say that it is not stretchy, it's challenging for systems to not assert or communicate that the fabric is "stretchy" over not "stretchy".

Incorporating Uncertainty with Concrete Information

Our system captures descriptions of materials, but there are many other systems and interfaces, such as fabric store search interfaces, that rely on professional-grade categories and standards. How do we incorporate uncertainty with these more concrete categories and standards? How do we clearly distinguish between qualities and categories? More importantly, how do these different kinds of information work together to help the user make sense of materials?

Design Challenge: Representing Consensual Truth

Given the complex nature of ambiguity in design domains, training participants to understand consensus, or having different representations of consensus may help users make sense of the ambiguity better. Our systems and representations rely on size to show some level of consensus, and have that be more visually apparent than other less-used descriptors.

If designers focus on communicating consensus, the user may not have many opportunities to negotiate and apply their own understanding of the fabrics. After all, if the user is trained to value consensus, then lesser used descriptors would have less value than what the majority thinks. Yet, one descriptor or phrase can illustrate the best picture of the fabric, that may not be seen in the consensus. We warn designers to be cautious in representing consensus and the implications for favoring the consensus over their own interpretation and language.

8.2 Design Guidelines for Ambiguity-Driven Domains

From lessons learn in the prior studies, below are user interface guidelines for designers working in ambiguity-focused domains, like in design.

8.2.1 Importance of Communication

Given the nature of ambiguity in these domains, it's imperative to design ways to communicate each of the following aspects:

1. Qualities versus Categories: Users may think of a descriptor as a category, but switch to thinking of it as a quality, without them aware of it.
2. Uncertainty: This communication applies to the processing, visualizing, interacting with, and incorporating existing data, of the uncertainty.
3. Consensus: In the ambiguity interfaces study, we communicated to participants that the ambiguity was based on people describing the fabric. We employed heavy use of the word "people" and included people icons, along with multiple explanations in the moderator's script. Yet, participants thought the percentages and people saying the descriptors described the material directly, rather than consensus.

The descriptor words versus phrases

The descriptor words may be used to access information, but phrases communicate context. While we did not find significant differences between experts and everyday participants, we found that incorporating phrases in the design helped participants make sense of fabrics. We incorporated phrases in the detailed view, and participants better understood the individual words.

8.2.2 Ambiguity in its role in design

The literature strongly supports the important of ambiguity in design. But, this value is one that is not shared by all practitioners. That is, ambiguity as a resource for design is a value statement that may not be shared by all practitioners. The user may be specific kind of builder, designer, stitcher or otherwise practitioner, that works with design constraints and need concrete information their materials.

8.2.3 Consider the uncertainty and its role in the user's values

Users may value some parts of the interface depending on whether they value what they can see, what others say about the ambiguity, or a combination of both. It's not always clear that the visual information is always correct, given the incorrect assertions of satin to be raw silk, and stretchy fabric to be a knit.

The user's values played a bigger role in this study than anticipated. Anecdotally, when asked about how they explore fabric stores with a store employee, some participants spoke of placing value in employees and owners of smaller fabric stores than bigger JoAnn store employees, independent of the employee's credentials.

Additionally, the user may engage in their practice as a solitary or collaborative endeavor, where the user may or may not need to negotiate meaning with others.

Another role that changes a user's values are any design constraints on a project, or the project itself. While all participants mentioned having a diverse set of experiences with fabric, one exclaimed to work almost exclusively with cottons, and thus prioritize fiber content and composition first, and then prioritize visuals. When the project calls for constraints, the user may not value navigating and negotiating through ambiguity, especially if the constraint is something they deem as concrete.

If the system were replaced by a person, what would system's response be if the user says that they do not believe them, and would rather see a video? While this design question is its own challenge itself, we suspect that placing value in what they see applies to particular craft domains that have design constraints in materials.

This system uses the language of users. It doesn't employ catalog quality descriptors. So design domains that thrive on negotiation and communication may find such ambiguity-filled systems more appealing than others.

We recommend designers to incorporate mechanisms that guide users to rely on and value different parts of the interface.

8.2.4 Domain specificity is a potential but not key resource

While domain-specific terms and ways of understanding may be useful, we found significant overlap of vocabulary between a wide variety of expertise and design and craft domains. We could not see an argument for designing domain-specific systems for description because of the limited nature of vocabulary.

Chapter 9

Conclusions & Future Work

In this document, we have explored the kinds of ambiguities present in design domains. We have found that one descriptor can be interpreted in many ways, while one descriptor can have multiple meanings. While this ambiguity is valued in design domains, such descriptors presents opportunities for technology in designing novel interfaces for exploring materials.

Our most important research question became: How can we design interfaces with standard interface toolkits to help designers explore and understand material remotely?

Our approach was to better understand the descriptions and the resulting ambiguities in describing fabric. Then we conducted empirical studies on how participants of diverse experiences and skillsets, describe different digital representations of materials. We also designed and implemented interfaces inspired from design practices. With the interface, we studied how practitioners explored fabric remotely and how they negotiated the ambiguities in the materials' description. From all studies, we deliver design guidelines to support interface designers focused in ambiguous-focused domains like design.

Our first contribution is an improved understanding of how people describe materials, through our empirical studies. Our second contribution, the resulting design guidelines, help user interface designers build better interfaces in communicating materials, their descriptors, and ambiguities for designers of varying skill levels.

Future work leads to further iterations on our various representations and interfaces, improving on prior designs. This work investigated the synergy of various interactions and representations with fabric, but we did not yet investigate how those interactions and representations help augment information to quantitative descriptions or professional-standards of the fabrics, such as percentage of fiber content and the specific weave type.

Future work can investigate how users interact with uncertain information and the quantitative information together. A potential collaboration with a fabric store can lead to compelling designs grounded in practice. If the fabric store has an online store, we can crowdsource descriptors and design a system that can study how users make sense of descriptors, along with the quantitative or professional-grade standard information.

Additionally, we are also interested in studying how participant's solo and collaborative creative endeavors influence their engagement with someone else's interpretations. A user's solo or collaborative practices may have influence how they value others' descriptions. There is potential to use crowdsourcing techniques as a way to reach many hobbyists, builders and designers with a variety of solo and collaborative creative experiences.

Future work also employs collaboration more actively between people who participated in the earlier description phase of the studies. This work already found different ambiguities in involved in material description. What remains is how to better understand what someone meant when they used a specific word.

To better extract meaning and intent behind a word, future work can investigate people describing the same fabric, and design technology to collaboratively encourage dialogue and sense making when they use the same word. For example, technology could encourage dialogue between two people using the word "soft", and spur conversation like: "well, when I meant soft, I meant soft in texture. Did you mean soft as in, soft in drape?".

Our studies focused on asking people to describe materials, which we assume are the most salient qualities. But, any one of these participants could have given only unique descriptors, or to make it searchable, or to share their own interpretation of those qualities. Further investigation can look aways to guide the inquiry that would better provide helpful information to designers, craftsman and builders of materials.

Revisiting the discussion from word-level to phrase-level ambiguity, future work can also investigate designs that further incorporate phrases to make them more prevalent. Once those designs are in, we can study how users' values in visual and descriptor information change, and hopefully find better usage between these kinds of information. Additionally, we can also do further studies to design more dialogue, conversation and negotiation between the system and the user. One potential design is to model dialogue closer to a helpful conversation between a user and their colleague.

Designs may also be visited from visual perspective as well. One of the pieces that could use more iterations is communicating descriptors to users in these designs. The graph of words may be overwhelming, and clustering algorithms and other visualizations may better support and represent descriptors.

With our findings, our goal is to better design technologies that support ambiguous interfaces, including supporting the designers in their exploration of materials.

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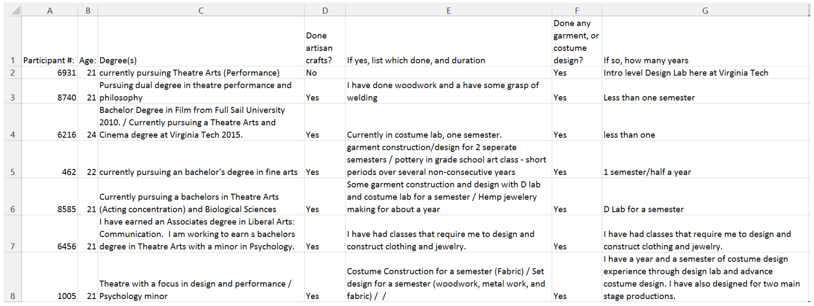
Appendix A

Study 1 Task Data: Exploratory Designers Study

A.1 Pre-questionnaire data



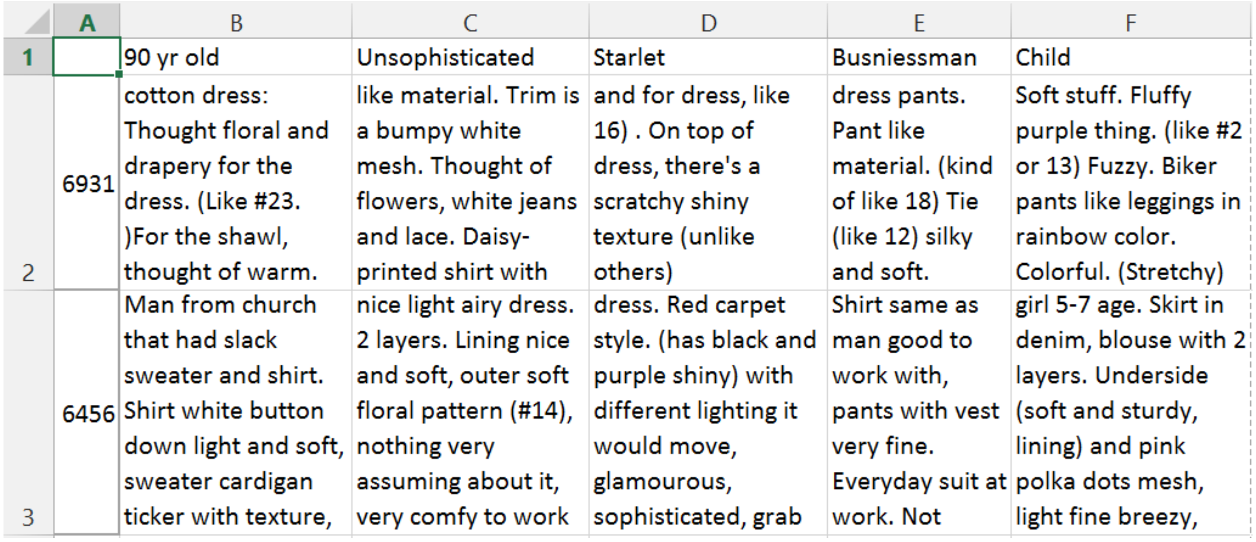
	A	B	C	D	E	F	G
1	Participant #:	Age:	Degree(s)	Done artisan crafts?	If yes, list which done, and duration	Done any garment, or costume design?	If so, how many years
2	6931	21	currently pursuing Theatre Arts (Performance)	No		Yes	Intro level Design Lab here at Virginia Tech
3	8740	21	Pursuing dual degree in theatre performance and philosophy	Yes	I have done woodwork and a have some grasp of welding	Yes	Less than one semester
4	6216	24	Bachelor Degree in Film from Full Sail University 2010. / Currently pursuing a Theatre Arts and Cinema degree at Virginia Tech 2015.	Yes	Currently in costume lab, one semester.	Yes	less than one
5	462	22	currently pursuing an bachelor's degree in fine arts	Yes	garment construction/design for 2 seperate semesters / pottery in grade school art class - short periods over several non-consecutive years	Yes	1 semester/half a year
6	8585	21	Currently pursuing a bachelors in Theatre Arts (Acting concentration) and Biological Sciences	Yes	Some garment construction and design with D lab and costume lab for a semester / Hemp jewelery making for about a year	Yes	D Lab for a semester
7	6456	21	I have earned an Associates degree in Liberal Arts: Communication. I am working to earn s bachelors degree in Theatre Arts with a minor in Psychology.	Yes	I have had classes that require me to design and construct clothing and jewelry.	Yes	I have had classes that require me to design and construct clothing and jewelry.
8	1005	21	Theatre with a focus in design and performance / Psychology minor	Yes	Costume Construction for a semester (Fabric) / Set design for a semester (woodwork, metal work, and fabric) / /	Yes	I have a year and a semester of costume design experience through design lab and advance costume design. I have also designed for two main stage productions.

Figure A.1: Data from our pre-questionnaires, asking about education level and experiences with design and craft.

A.2 Fabrics swatches in experiment

Figure A.2: Our wide selection of fabrics and textures recommended from our local expert. The numerical order in this list, starting from the top left to right, top to bottom, is the same order in reference to the rest of the data.

A.3 Task 1 data



	A	B	C	D	E	F
1		90 yr old	Unsophisticated	Starlet	Busniessman	Child
2	6931	cotton dress: Thought floral and drapery for the dress. (Like #23.)For the shawl, thought of warm.	like material. Trim is a bumpy white mesh. Thought of flowers, white jeans and lace. Daisy-printed shirt with	and for dress, like 16) . On top of dress, there's a scratchy shiny texture (unlike others)	dress pants. Pant like material. (kind of like 18) Tie (like 12) silky and soft.	Soft stuff. Fluffy purple thing. (like #2 or 13) Fuzzy. Biker pants like leggings in rainbow color. Colorful. (Stretchy)
3	6456	Man from church that had slack sweater and shirt. Shirt white button down light and soft, sweater cardigan ticker with texture,	nice light airy dress. 2 layers. Lining nice and soft, outer soft floral pattern (#14), nothing very assuming about it, very comfy to work	dress. Red carpet style. (has black and purple shiny) with different lighting it would move, glamourous, sophisticated, grab	Shirt same as man good to work with, pants with vest very fine. Everyday suit at work. Not	girl 5-7 age. Skirt in denim, blouse with 2 layers. Underside (soft and sturdy, lining) and pink polka dots mesh, light fine breezy,

Figure A.3: Both participants' data for the first task.

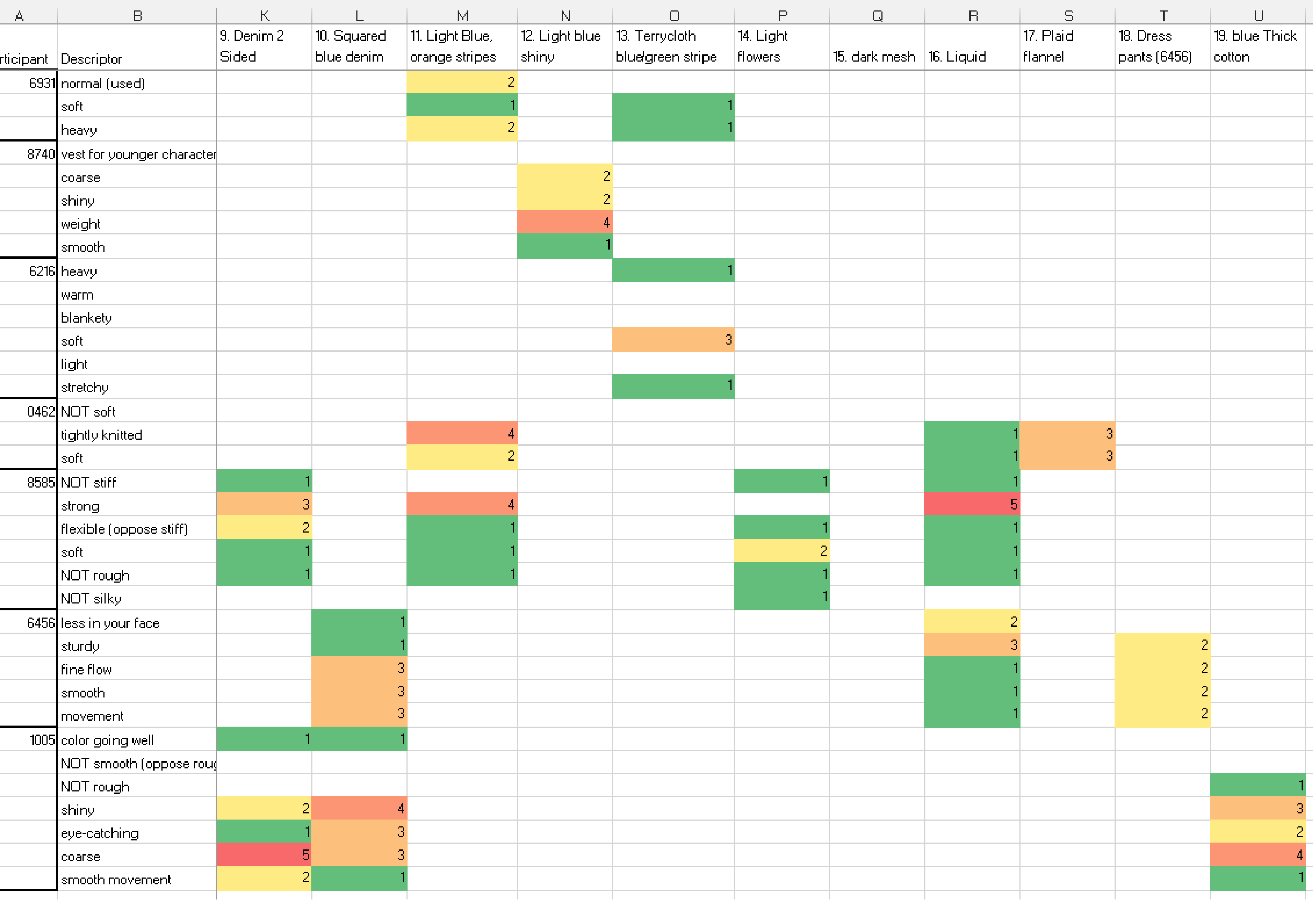
A.4 Task 2 data

For the full set of responses, please see the link: Data Spreadsheet Link

A.4.1 Comparison data

	A	B	C	D	E	F	G	H	I	J
1	Participant	Descriptor	1. Chanel	2. Pink	3. Checkerboard	4. 2-Toned Rose	5. Brocade Rose	6. Orange	7. Green/Pink Plaid	8. Grey Denim
2	6931	normal (used)							1	
3		soft							2	
4		heavy							3	
5	8740	vest for younger character			1		2			
6		coarse			1					
7		shiny			3		1			4
8		weight			3		2			1
9		smooth			2		3			4
10	6216	heavy	1	2						
11		warm	1	2	3					
12		blankety	1							
13		soft	3	2	1					
14		light			1					
15		stretchy	2							
16	0462	NOT soft								1
17		tightly knitted								2
18		soft								4
19	8585	NOT stiff			1		1			
20		strong			2		1			
21		flexible (oppose stiff)			2		3			
22		soft			2		2			
23		NOT rough			1		1			
24		NOT silky								
25	6456	less in your face								
26		sturdy								
27		fine flow								
28		smooth								
29		movement								
30	1005	color going well								1
31		NOT smooth (oppose rough in texture)								1
32		NOT rough								
33		shiny						1		2
34		eye-catching						1		
35		coarse					2	1		3
36		smooth movement					4	5		3

Figure A.4: Chart of each participant's response to any description when asked to compare or group different fabrics.(Part 1 Green or 1 exemplifies the most from the descriptor, such as most soft, while red or a high number represents the least of that descriptor. Descriptors that are negations also count.

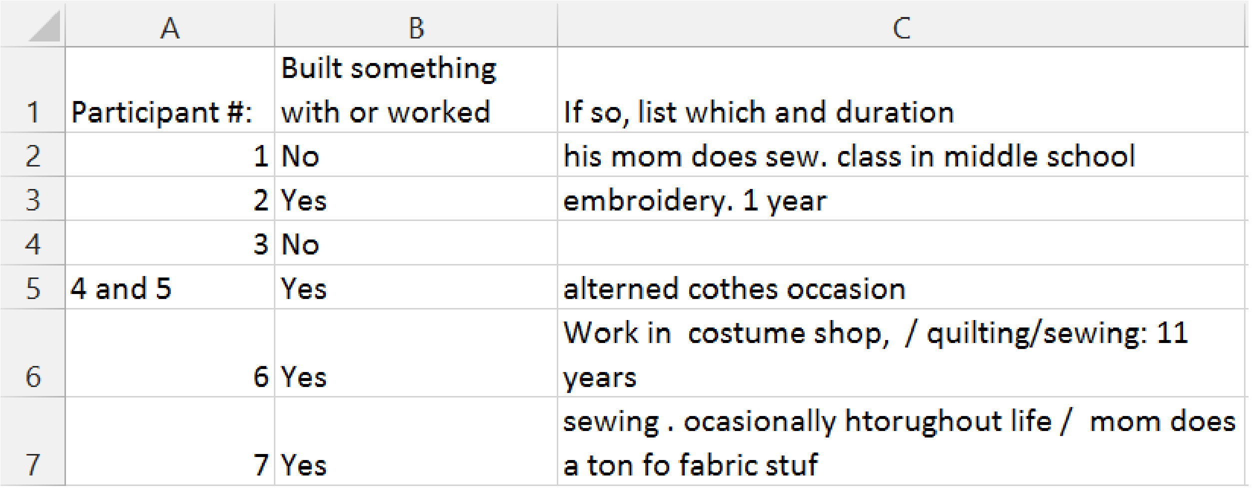


A	B	K	L	M	N	O	P	Q	R	S	T	U
rticipant	Descriptor	9. Denim 2 Sided	10. Squared blue denim	11. Light Blue, orange stripes	12. Light blue shiny	13. Terrycloth blue/green stripe	14. Light flowers	15. dark mesh	16. Liquid	17. Plaid flannel	18. Dress pants (6456)	19. blue Thick cotton
6931	normal (used)			2								
	soft			1		1						
	heavy			2		1						
8740	vest for younger character											
	coarse				2							
	shiny				2							
	weight				4							
	smooth				1							
6216	heavy					1						
	warm											
	blankety											
	soft					3						
	light											
	stretchy					1						
0462	NOT soft											
	tightly knitted			4					1	3		
	soft			2					1	3		
8585	NOT stiff	1					1		1			
	strong	3		4					5			
	flexible (oppose stiff)	2		1			1		1			
	soft	1		1			2		1			
	NOT rough	1		1			1		1			
	NOT silky						1					
6456	less in your face		1						2			
	sturdy		1						3		2	
	fine flow		3						1		2	
	smooth		3						1		2	
	movement		3						1		2	
1005	color going well	1	1									
	NOT smooth (oppose roug											
	NOT rough											1
	shiny	2	4									3
	eye-catching	1	3									2
	coarse	5	3									4
	smooth movement	2	1									1

Appendix B

Study 2 Task Data: Exploratory Everyday Study

B.1 Pre-questionnaire data



	A	B	C
1	Participant #:	Built something with or worked	If so, list which and duration
2	1	No	his mom does sew. class in middle school
3	2	Yes	embroidery. 1 year
4	3	No	
5	4 and 5	Yes	alterned cothes occasion
6	6	Yes	Work in costume shop, / quilting/sewing: 11 years
7	7	Yes	sewing . ocasionally htorughout life / mom does a ton fo fabric stuf

Figure B.1: Pre-questionnaire data from our second experiment

B.2 Task data

For the full set of responses, please see the link: Data Spreadsheet Link

Appendix C

Crowdsourcing Study Data

This section of the appendix discusses the first crowdsourcing project as a technical document. Originally, this document was a part of a final class project, and for this thesis, it serves as a guide to how to accomplish similar kinds of code that have been essential for running the various studies described in this document, from Qualtrics code to R analysis code.

This technical document describes the project with respect to the technical aspects involved with forming surveys on Qualtrics, connecting the survey to Amazon Turk, and analysis. This project did not result in a full system, but a significant amount of code formed the survey to meet the desired experimental design and process all data collected.

This document outlines the following, in order accomplished in the project:

1. **Section 2: Qualtrics Survey Formation:** Given the specific experimental design, I used the features in Qualtrics with Javascript to generate the survey I wanted. After the survey was set, I made another copy of the survey so that the crowdsourced and the live participants each had a unique survey to fill out.

2. **Section 3: Connecting a Qualtrics Survey to Amazon Turk** This section outlines how I connected Qualtrics with Amazon Turk. This section has very little code, but nonetheless is a guide for how this process was done.

3. **Section 4: Analysis:** After collecting all the data, I used R to pre-process and clean the data, and to analyze the data and generate many of the graphs in my presentation and in the final paper document.

4. **Section 5: Document Appendix** This section contains code snippets that may have

been too big to include in the document itself, along with links to the data and the videos made.

C.1 Connecting a Qualtrics Survey to Amazon Turk

Our experimental design involved the following qualities:

1. **Amazon Turk Workers versus live participants.** Our live participants also filled out the same survey as the Turk workers.
2. **Size.** In order to test how size affected participants' responses, we needed to vary the fabric in size between a large and small size. I chose to put each participant in a bucket, starting with 0 small fabrics up to all small fabrics, distributed evenly and in order of participants. The first participant would get 0 small fabrics, the second would get 1 small fabric and 4 big fabrics, for example.
3. **Fabrics.** I had a variety of 22 fabrics. 18 of those fabrics were cut with a big and small size, while 4 ones were only small.

This section outlines how we accomplished the above experiment. In summary, I tackled each aspect in the following ways:

1. To separate out the online versus live participants, I had two duplicate surveys, one per group.
2. Qualtrics does not allow you to re-select conditions based on how many participants have taken they survey. However, it does have a mechanism to assure that some conditions are evenly distributed throughout the participants, to at least guarantee that the first 6 participants have done all varieties of fabric size distributions, from all big fabrics to all small fabrics. Below are the steps to accomplish the above task, step by step. The only aspect that I do not explain much are the exact details of generating Qualtrics survey questions and pages in the survey. I found those very easy and straightforward, so this section details the more challenging aspects of building this particular kind of survey.

C.1.1 Initialize extra variables

Qualtrics supports embedded data, which are extra variables and conditions set by the researcher. In order to add embedded data in Qualtrics, click on Survey Flow under Edit survey, as shown in figure C.1.

After clicking on “Survey Flow”, embedded data can be added to a survey. Figure C.2 is a snapshot of some of the embedded data needed. I added 28 embedded data variables that covered the condition selected for the participant, the fabric numbers and sizes selected, urls to the corresponding fabrics, and the descriptors used in the ranking portion of the survey. Each one of these variables were added in manually, since Qualtrics does not provide an automated way to generate embedded data.

This embedded data was declared at the beginning of the survey. Instantiation of these variables will come after the first page where the consent form is posted.

After the embedded data is set, I made a block that just shows the consent form and a “Next” button. A block is how Qualtrics sets pages in a survey.

C.1.2 Set the fabric sizes

After the participant finishes with the first page, I calculate what kind of fabric size distribution will the participant see. I initially wanted the first participant to have 0 small fabrics and 5 big fabrics, then the second participant have 1 small fabric and 4 big fabrics, and so on. I wanted to be sure that all my size conditions were covered evenly, no matter how many participants I got.

Qualtrics does not support the precision of this kind of bucketing, but it can generally guarantee that the first six participants span all conditions. First, I added a randomizer. The randomizer was set to evenly present the elements, so all the conditions were shown throughout the participants. Then, depending on the resulting number, the embedded data *conditionType* was set to a number from 0 to 5, and this number represents how many small fabrics the participant will see. Figure C.3 is a screenshot of the result.

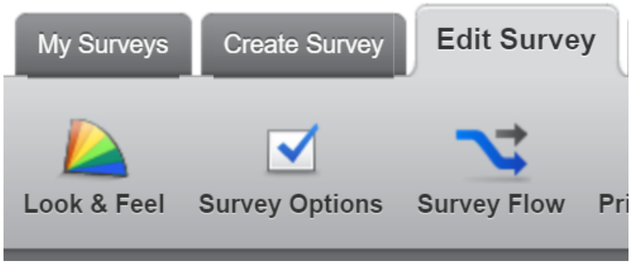
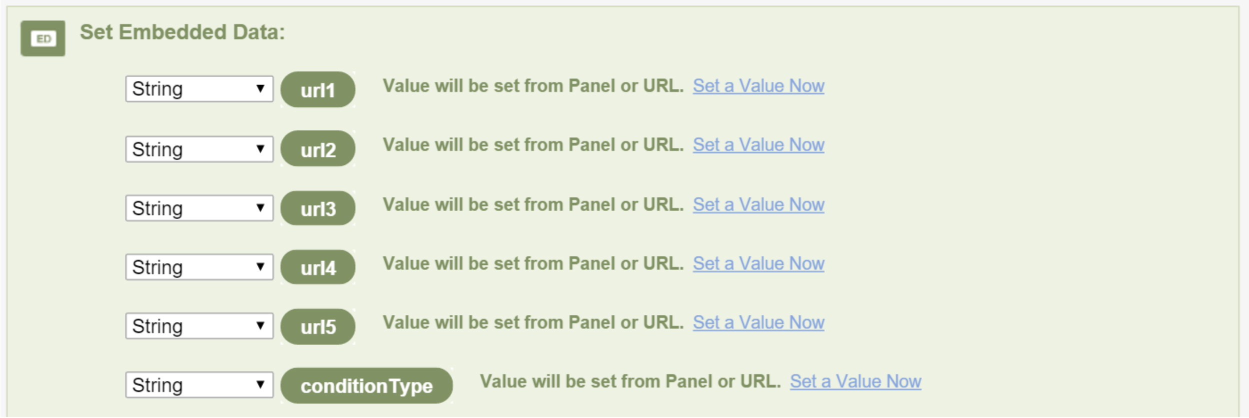


Figure C.1: Screenshot of Qualtrics’s main menu on the upper left hand side of the screen. To add embedded data, click on “Survey Flow”.



Set Embedded Data:

String url1 Value will be set from Panel or URL. Set a Value Now

String url2 Value will be set from Panel or URL. Set a Value Now

String url3 Value will be set from Panel or URL. Set a Value Now

String url4 Value will be set from Panel or URL. Set a Value Now

String url5 Value will be set from Panel or URL. Set a Value Now

String conditionType Value will be set from Panel or URL. Set a Value Now

Figure C.2: A partial list of the embedded data set by hand in Qualtrics.

C.1.3 Instantiate the embedded data variables

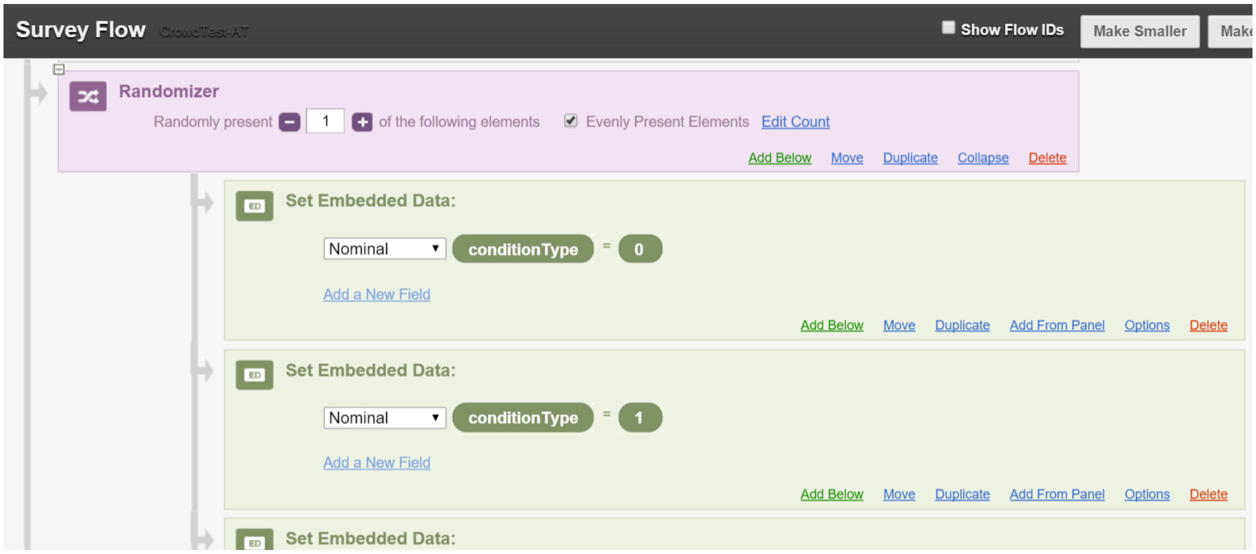
After calculating how many small and large fabrics the participant got, I had to select the fabrics randomly, along with storing the appropriate fabric video URL. While I could have used the randomizer for this task, I wanted to be sure that the same fabric was not shown twice. That is, I did not want a participant to see both a big or small version of the same fabric. The prior strategy did not work to ensure this constraint, so I had to build a script that would enforce this.

In Qualtrics, one of the few ways to inject Javascript code into a survey is when a page is loaded. I chose to pick fabrics on a page where I simply showed an example of how to describe fabrics.

I manually wrote up a Dictionary/Map in Javascript that translated a fabric's ID number to its corresponding video URL. Then I randomly picked small fabrics equal to the condition number, then picked big fabrics that are not the same as the small fabrics. For the code itself, please refer to Appendix C.4.1.

C.1.4 Loop and Merge to ask the same question on different fabrics

Loop and Merge is a feature in Qualtrics that allows researchers to ask the same question, multiple times, varying on some data. This feature can be added onto any question. I chose to add it to my fabric description question, varying on the fabric URLs that were selected in the prior step. Figure C.4 is a screenshot of my settings for this feature.



Randomizer

Randomly present 1 of the following elements ☑ Evenly Present Elements Edit Count

Set Embedded Data:

Nominal conditionType = 0

Set Embedded Data:

Nominal conditionType = 1

Set Embedded Data:

Figure C.3: A screenshot of how I approximated bucketed conditions in my survey for fabric size.

Validation of data

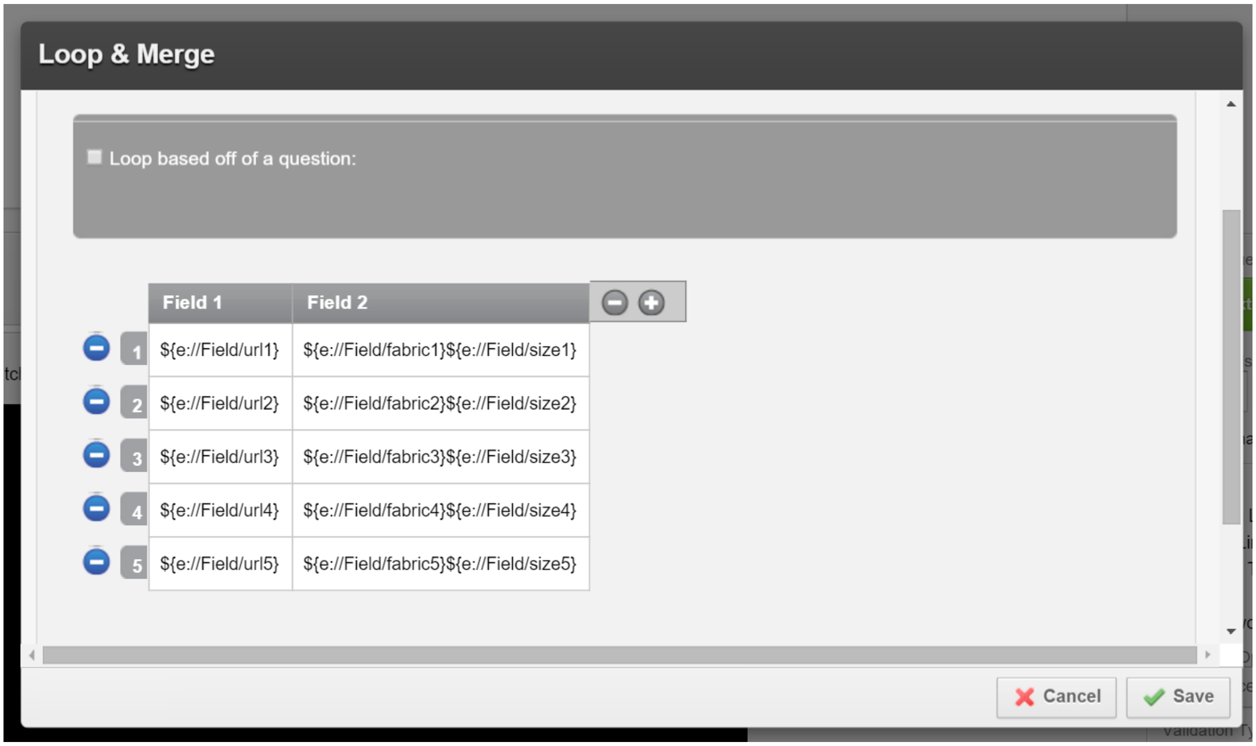
Qualtrics provided some validation features to prevent participants from giving me bad data. For example, I made participants fill out some content for the first 3 text boxes, ensuring I had 3 descriptors.

Additionally, I used Qualtrics's custom validation to be sure participants did not enter the same descriptor on the 3 text boxes. Researchers could add specific requirements through a series of drop-down menus specifying the conditions in which data is valid.

Figure C.5 is a screenshot of how I made sure participants were not entering the same thing for any of the 3 text boxes. In summary, each line represents a boolean statement indicating whether:

1. the first, second are third descriptor is not an empty string
2. the first descriptor != second descriptor
3. the first descriptor != third descriptor
4. the second descriptor != third descriptor

Unfortunately, Qualtrics did not have a mechanism to check whether participants inputted the same descriptors for all fabrics. It was understandable if a participant thought some of the fabrics were soft, but not every single one. Unfortunately there was no way to check for that kind of validation.



☐ Loop based off of a question:

	Field 1	Field 2
1	${e://Field/url1}	${e://Field/fabric1}${e://Field/size1}
2	${e://Field/url2}	${e://Field/fabric2}${e://Field/size2}
3	${e://Field/url3}	${e://Field/fabric3}${e://Field/size3}
4	${e://Field/url4}	${e://Field/fabric4}${e://Field/size4}
5	${e://Field/url5}	${e://Field/fabric5}${e://Field/size5}

Figure C.4: A screenshot of how the same question was asked multiple times, for different fabric videos, using Qualtrics's *Loop and Merge* feature. This mechanism picked items from the column Field 1 at random. Each one of the items in Field 1 is an embedded data variable that had a video URL.

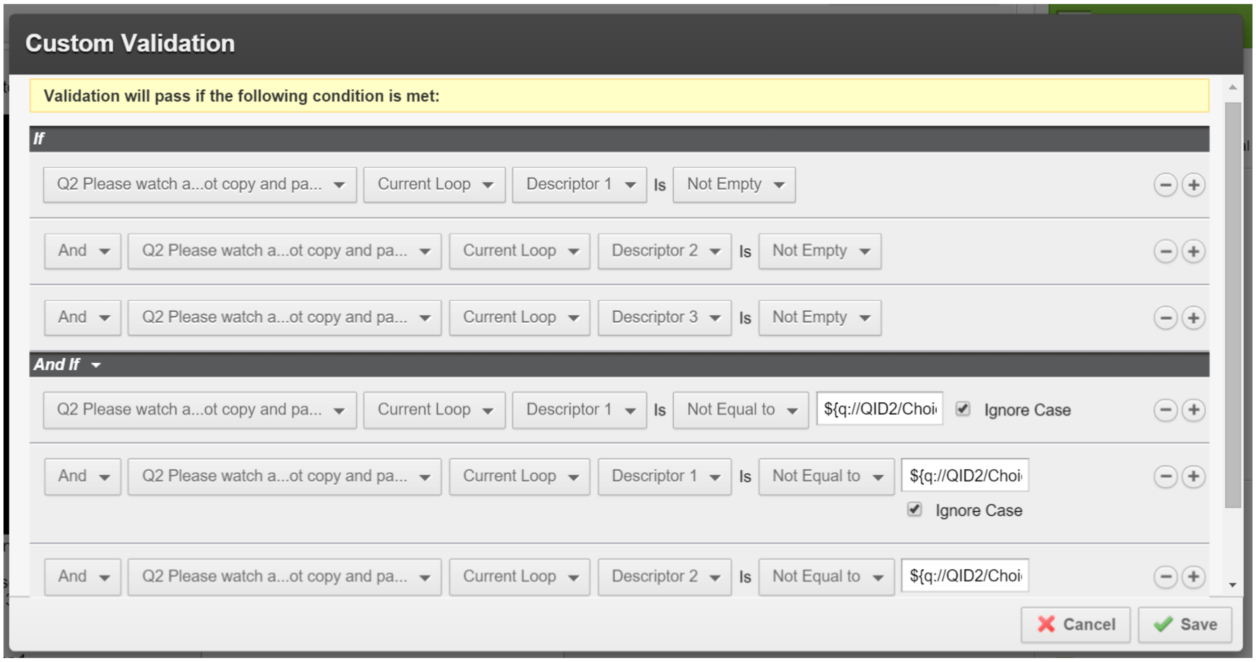
C.1.5 Select descriptors from participant's responses

After the participant finished describing all fabrics, I wrote code that randomly selected a participant's own descriptors.

I added n page that had an example of how to rate the fabrics. This page served both to instruct participants on how the rating and grouping should happen ans as a place I can execute code collect all the descriptors and randomize them.

Participants could, in theory, put the same 3 words in all fabrics. There would only be 3 unique descriptors instead of 6. To be certain I got valid data, if there were not enough unique descriptors for the participants to rate, I added the top 6 most popular descriptors from prior studies, and added descriptors to be sure the participant had 6 descriptors to rate the fabrics on. The full code is in Appendix C.5.

When participants rated and grouped fabrics, I had simple validation to be sure that all fabrics were rated and grouped.



Custom Validation

Validation will pass if the following condition is met:

If

Q2 Please watch a...ot copy and pa... Current Loop Descriptor 1 Is Not Empty

And Q2 Please watch a...ot copy and pa... Current Loop Descriptor 2 Is Not Empty

And Q2 Please watch a...ot copy and pa... Current Loop Descriptor 3 Is Not Empty

And If

Q2 Please watch a...ot copy and pa... Current Loop Descriptor 1 Is Not Equal to ${q://QID2/Choi ☑ Ignore Case

And Q2 Please watch a...ot copy and pa... Current Loop Descriptor 1 Is Not Equal to ${q://QID2/Choi ☑ Ignore Case

And Q2 Please watch a...ot copy and pa... Current Loop Descriptor 2 Is Not Equal to ${q://QID2/Choi

Figure C.5: A screenshot of how I made sure participants did not provide the same descriptor twice.

C.2 Qualtrics - Amazon Turk

After completing the survey, the survey needed to be connected to Amazon Turk. I used a HIT that had a survey link and required participants to copy and paste a survey code given at the end of the survey, back to Turk.

I relied on online resources to guide me through the process. In particular, this site (http://brentcurdy.net/qualtrics-tutorials/link/) was the most helpful in using Qualtrics to generate a unique random number per participant, showing that number to the participant at the end of the survey, and setting up the Survey with link HIT. Below is a screenshot of the functionality I used to generate a unique random code, from Qualtrics under *Edit Survey -> Survey Flow*:

In testing my HIT, after accepting the HIT, the whole page would redirect me to the survey, and after finishing the survey, there was no easy way to go back to the HIT page. So, I needed to go to the HIT page, access the HTML code, and added the following element to the survey link:

```
target="_blank"
```

After a worker accepts the HIT and clicks on the link, the survey would pop up in another page, leaving the original HIT page open.

C.2.1 Analysis

The majority of analysis of the data was done in R. This section is a walk through of all the code. For a zip file link for all code, please see Appendix C.3.2.

C.2.2 Loading data

Qualtrics outputted data in a .csv file, and my live participant transcriptions were stored in an excel file that I converted into a .csv file. R

LoadData.R loaded the csv files into files used in R. Below is a code snippet of how an individual file was loaded into R:

```
dTurk =read.csv("fabric-ATOnline.csv",header = FALSE)
colClasses=c("NULL",rep(NA, 20)))
corpusT <- Corpus(DataframeSource(data.frame(dTurk)))
txtT<- tm_map(corpusT, content_transformer(tolower))
txtT<- hardClean(txtT)
dtmT <- (DocumentTermMatrix(txtT))
```

C.2.3 Pre-processing

hardClean.R provides functions to clean up the data and remove or substitute in pieces of data. This data also converts all words to root words.

There are two main tasks for clean-up: remove useless words , and categorize some words by replacing them with useful words.

The script itself is a long function, so below are some snippets for each section.

Removals

I removed filler words, verbs, articles, misspellings, and nouns that were not relevant to fabric itself, like numbers, “thing” and others like it. Below is a sample of what I removed from that category.

```
  text<- tm_map(text, removeWords, c("almost", "good", "suitabl
     ", "similar", "spectrum", "relat", "opposit", "mind", "
     charact", "compar", "portion", "well", "due", "help", "
```

```
    lapel", "arrang", "specif","get","goe", "mean", "sure","
    pick","even", "verymost", "midrd", "someth", "midmost","
    say", "made", "make", "whiel", "thing", "think", "rdmid",
    "since", "sinc", "least", "maybe", "less", "though"," less
    ", "like","along","also", "vest", "better","worse","doesnt
    ","dont", "realli", "cant", "can",  "use", "very", "most",
     "wouldnt", "one", "person", "enough", "dyad", "look", "
    kind", "differ", "either", "instead", "mid"))
text<- tm_map(text, removeWords, c("another", "little", "
    pretty","bit", "much","may", "ofa", "might", "probably", "
    probabl", "still", "your", "seem", "definit", "see", "way
    ", "there", "kidn", "lot", "got"))
```

Fix the data

There are a few main reasons why raw data was changed. The first is if the stemming process did not occur correctly and stemmed words were not grouped together. I also changed the data to fix for common misspellings.

Some data needed to be grouped together, like color. This research does not explore ambiguity in color, so there is no difference whether one participant called a piece of fabric “lime green” versus “green” versus “forest green”. What was important was that the participant made a reference to color.

Below shows code snippets that show some of these substitutions to change the initial data.

```
text<-tm_map(text, cString, "smoother", "smooth")
text<-tm_map(text, cString, "smoothest", "smooth")
text<-tm_map(text, cString, "shinier", "shini")
text<-tm_map(text, cString, "shiniest", "shini")
text<-tm_map(text, cString, "coarser", "coars")
text<-tm_map(text, cString, "shine", "shini")
....................
text<-tm_map(text, cString, "rust color", "color")
text<-tm_map(text, cString, "rustic orang", "color")
text<-tm_map(text, cString, "pumpkin orang", "color")
text<-tm_map(text, cString, "lime green", "color")
```

C.2.4 Frequencies and Quantities

To calculate the most frequent words in each dataset, printCoOccurenceGraph.R has a function that outputs this information.

```
#tdm is a term-document matrix that all the data is converted
   into.
printFreqWords<- function (tdm)
{
  haveFreqMoreThan = 5 #The word must appear more than 5 times
  print(findFreqTerms(tdm, haveFreqMoreThan))

  #print out the top 7 words
  m <- as.matrix(tdm)
  v <- sort(rowSums(m), decreasing=TRUE)
  TopFreq = 7
  print(head(v, TopFreq))
}
```

After running these functions on all the data, I copied and pasted the numbers into Excel to make more aesthetically pleasing bar graphs.

C.2.5 Co-occurrence graphs

Inside printCoOccurenceGraph.R, the function printCoOccurenceGraph calculates a co-occurence graph and generates the graph. In general, I attribute the majority of this code to code I found online here: https://rdatamining.wordpress.com/2012/05/17/an-example-of-social-network-analysis-with-r-using-package-igraph/

The code first dropped words that were only mentioned once. Then, the code generated another matrix that showed whether a word was present in a comment. In this analysis, it is not important if a participant described a fabric as “thick” three times. The word “thick” was counted once if it was describing one fabric.

Then, a co-occurrence matrix was generated. If words were found in the same comment, those words are related in some way. The more often such words appeared in the same comment, the stronger the co-occurrence was. After the matrix was calculated the matrix was graphed.

C.2.6 Descriptor differences between groups

To detect descriptor differences between words, I relied on scripts on the following site:

http://blog.rolffredheim.com/2013/02/mapping-significant-textual-differences.html

I wanted to calculate if some words appeared significantly more in one group than another. The code generated a matrix that mapped words to counts in each of the datasets. I wanted to calculate the probabilities that each word appeared in each dataset. Then, I compared both a z-index comparison test and a 2-sided non-parametric CHI Squared test for on the frequency of each word in the dataset. I marked statistically significant data. Then, I graphed the words with respect to their probabilities in appearing in a graph.

C.3 Document Appendix

C.3.1 Survey

Below is a link to how the survey appeared to an Amazon Turk participant, along with extra associated data such as embedded data values at the end:

Here

C.3.2 R Scripts

Below is a link to a zip file containing all R scripts used for analysis:

Here

C.3.3 Videos

Below are two links for how a big and small fabric appears on video:

Big: Here Small: Here

C.3.4 Response Data

For this study, there were 3 conditions studied: live participants describing real fabric, live participants describing fabric online, and Amazon Turk participants describing fabric online.

For the resulting dataset, please see the full data zip file, containing a csv file for each one of these conditions.

C.4 Survey Code

C.4.1 Randomly selecting fabrics to describe

Below is javascript code inserted into Qualtrics to randomly select fabrics:

```
Qualtrics.SurveyEngine.addOnload(function()
{

        function getRandom(min, max) {
    return min + Math.floor(Math.random() * (max - min + 1));
        }

        function printArray(arr)
        {
                        //print just to check
                var c = 0;
                for(c= 0; c < arr.length; c++)
                {
                        console.log(c + ". "+arr[c]);
                }
        }

        function saveStudyEmbeddedData(urls, nums, size)
        {
                        //Save each URL to the embedded data
                Qualtrics.SurveyEngine.setEmbeddedData("url1",
                   urls[0]);
                Qualtrics.SurveyEngine.setEmbeddedData("url2",
                   urls[1]);
                Qualtrics.SurveyEngine.setEmbeddedData("url3",
                   urls[2]);
                Qualtrics.SurveyEngine.setEmbeddedData("url4",
                   urls[3]);
                Qualtrics.SurveyEngine.setEmbeddedData("url5",
                   urls[4]);

                //save the numbers
                Qualtrics.SurveyEngine.setEmbeddedData("fabric1
                   ",nums[0]);
                Qualtrics.SurveyEngine.setEmbeddedData("fabric2
                   ",nums[1]);
```

```
        Qualtrics.SurveyEngine.setEmbeddedData("fabric3
           ",nums[2]);
        Qualtrics.SurveyEngine.setEmbeddedData("fabric4
           ",nums[3]);
        Qualtrics.SurveyEngine.setEmbeddedData("fabric5
           ",nums[4]);

        //save the sizes
        Qualtrics.SurveyEngine.setEmbeddedData("size1",
           size[0]);
        Qualtrics.SurveyEngine.setEmbeddedData("size2",
           size[1]);
        Qualtrics.SurveyEngine.setEmbeddedData("size3",
           size[2]);
        Qualtrics.SurveyEngine.setEmbeddedData("size4",
           size[3]);
        Qualtrics.SurveyEngine.setEmbeddedData("size5",
           size[4]);
}

function genVideoMap()
{
        var map = new Map([["1s", "hB-D1vTsQDw"],
                                            ["2s", "1
                                               ecNMKucDl0
                                               "],
                                            ["3s", "
                                               FcIMmeOz9Bw
                                               "],
                                            ["4s", "
                                               eGCywQ2TA5E
                                               "],
                                            ["5s", "
                                               q2tGwoq0L
                                               -k"],
                                            ["6s", "968
                                               I1J7hVp0
                                               "],
                                            ["7s", "
                                               U8mx8FUPUyE
                                               "],
```

```
["8s", "
   m3tTdZHosG8
   "],
["9s", "
   EPFy3BF-
   My0"],
["10s", "3
   RU7sthrXnQ
   "],
["11s", "xd-
   qTuwG04s
   "],
["12s", "
   L7AE_rUCH3k
   "],
["13s", "4
   iY0Yiev27Q
   "],
["14s", "-
   osbEtVolfI
   "],
["15s", "
   ED0T7jqjPFU
   "],
["16s", "
   Oom2KpXeaqA
   "],
["17s", "
   mRxAHU-
   TT8g"],
["18s", "
   vldYb-8
   O3qI"],
["19s", "0
   l9b0OXrbEU
   "],
["20s", "
   BIa1is_WA5U
   "],
["21s", "
   xjcTCN7WvWQ
   "],
```

```
["22s", "
   udD7ua3Jgd4
   "],
["1b", "
   AU821MEIMjA
   "],
["2b", "
   um2VTnjMPHk
   "],
["3b", "
   aAvsWLyZW0A
   "],
["4b", "1
   plXXqRDY7Q
   "],
["5b", "
   dVI8oZIQoHQ
   "],
["6b", "1
   ptdauPXmP4
   "],
["7b", "
   i5ALeEn0Jw8
   "],
["8b", "
   m5eJcywseuY
   "],
["9b", "
   YFv5gQZY_KM
   "],
["10b", "
   p0awuFV4m0o
   "],
["11b", "67
   gsWpXgCr8
   "],
["12b", "
   qN30iQv8-
   wE"],
["13b", "9
   UXQbDwFea8
   "],
```

```
                                                ["14b", "
                                                  x1W4XEStELE
                                                  "],
                                                ["15b", "
                                                  oewTceTngz4
                                                  "],
                                                ["16b", "
                                                  HIkbSVIBC2w
                                                  "],
                                                ["17b", "
                                                  ZLU0S7nXksk
                                                  "],
                                                ["18b", "
                                                  z7qnc5LYzzk
                                                  "]
                                               ]);
            return map;

    }

    //set the participant number
    var participantNumber = Math.floor((Math.random()*1000)
        + 1000);
Qualtrics.SurveyEngine.setEmbeddedData("participantNumber",
   participantNumber);


    var numSmalls = parseInt("${e://Field/conditionType}")
       ;//Qualtrics.SurveyEngine.getEmbeddedData('
       conditionType');
    var fabricNums =
       [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22];

    var r = 0, a = 0, b = 0;
    var fabricUrls = [], fabricSizes = [], fabricOrder =
       [];
    var numToUrl = genVideoMap();
    console.log("Print");
    console.log("Num smalls: " + numSmalls + ", " + typeof(
       numSmalls));

    //get the correct number of small fabrics
```

```
for(a = 0; a < numSmalls; a++)
{
        //console.log(r + "print");
        r = getRandom(0, fabricNums.length - 1);
        //console.log(r + "print");
        fabricUrls.push(numToUrl.get(fabricNums[r] + "s
           "));
        fabricOrder.push(fabricNums[r]);
        fabricSizes.push("s");
        fabricNums.splice(r, 1);
        console.log(fabricNums[r] + "Small");

}

printArray(fabricUrls);

//get the correct number of big fabrics
for(b = 0; b < 5 - numSmalls; b++)
{
        r = getRandom(0, fabricNums.length - 1);
        //if the number does not have a big complement
           (id > 19) restart the randomiation
        if(fabricNums[r]  > 18)
        {
                b--;
                console.log("Invalid fabric");
        }
        else
        {
                //fabricUrls.push(fabricNums[r] + "b");
                fabricOrder.push(fabricNums[r]);
                fabricUrls.push(numToUrl.get(fabricNums
                   [r] + "b"));
                fabricSizes.push("b");
                fabricNums.splice(r, 1);
                //fabricUrls.splice(r, 1);
                console.log(fabricNums[r] + "Big");
        }
}

printArray(fabricUrls);
```

```
        //console.log("Before: 1. "+ "${e://Field/url1}" + ", "
           + "${e://Field/url2}" + ", " + "${e://Field/url3}"
           + ", " + "${e://Field/url4}" + ", " + "${e://Field/
           url5}");

        saveStudyEmbeddedData(fabricUrls, fabricOrder,
           fabricSizes);

        //console.log("After: 1. "+ "${e://Field/url1}" + ", "
           + "${e://Field/url2}" + ", " + "${e://Field/url3}" +
            ", " + "${e://Field/url4}" + ", " + "${e://Field/
           url5}");


}



);
```

C.5 Randomly selecting descriptors

Below is javascript code inserted into Qualtrics to randomly select descriptors:

```
Qualtrics.SurveyEngine.addOnload(function()
{
        function getRandom(min, max) {
    return min + Math.floor(Math.random() * (max - min + 1));
        }
        //prints an array to the console,
        function printArray(arr)
        {
                        //print just to check
                var c = 0;
                for(c= 0; c < arr.length; c++)
                {
                        console.log(c + ". "+arr[c]);
                }
        }
        //This function goes through the array, checks for and
           removes for duplicate entries.
```

```
function cleanArray(arr)
{
        var d = 0, e = 0;
        for(d= 0; d < arr.length; d++)
        {
                if(arr[d] === "")
                {
                        arr.splice(d, 1);
                        d--;
                }
                else//do clone checking
                {

                        for(e = 0; e < d; e++)
                        {
                                if(arr[e] === arr[d])
                                {
                                        arr.splice(d,
                                           1);
                                        d--;
                                        e = d;//get out
                                            of this
                                           loop.
                                }
                        }
                }
        }
}
//This function checks if there are enough unique
   descriptors provided. If not, add in the most
   popular descriptors from prior studies.
function getEnoughDesc(arr)
{
        if(arr.length < 6)
        {
                arr.push("smooth");
                arr.push("shiny");
                arr.push("rough");
                arr.push("soft");
                arr.push("flexible");
                arr.push("thick");
```

```
                cleanArray(arr);
        }


        //print just to check
        //var c = 0;
}
//saves all data to embedded data for Qualtrics to use.
function saveEmbeddedDesc(arr)
{
                        //Save each URL to the embedded
                           data
        Qualtrics.SurveyEngine.setEmbeddedData("comp1",
           arr[0]);
        Qualtrics.SurveyEngine.setEmbeddedData("comp2",
           arr[1]);
        Qualtrics.SurveyEngine.setEmbeddedData("comp3",
           arr[2]);
        Qualtrics.SurveyEngine.setEmbeddedData("comp4",
           arr[3]);
        Qualtrics.SurveyEngine.setEmbeddedData("comp5",
           arr[4]);
        Qualtrics.SurveyEngine.setEmbeddedData("comp6",
           arr[5]);
}

//${q://1_QID2/ChoiceTextEntryValue/1} ${q://1_QID9/
   ChoiceTextEntryValue/1}
//${q://2_QID2/ChoiceTextEntryValue/1}
//This line collects all descriptors from the prior
   questions.
var allDes = ["${q://1_QID2/ChoiceTextEntryValue/1}", "
   ${q://1_QID2/ChoiceTextEntryValue/2}",
                          "${q://1_QID2/
                             ChoiceTextEntryValue/3}",
                         "${q://1_QID9/
                            ChoiceTextEntryValue/1}", "
                            ${q://1_QID9/
                            ChoiceTextEntryValue/2}",
                         "${q://1_QID9/
                            ChoiceTextEntryValue/3}",
```

```
 "${q://2_QID2/
   ChoiceTextEntryValue/1}",
   "${q://2_QID2/
   ChoiceTextEntryValue/2}",
 "${q://2_QID2/
   ChoiceTextEntryValue/3}",
"${q://2_QID9/
  ChoiceTextEntryValue/1}", "
  ${q://2_QID9/
  ChoiceTextEntryValue/2}",
"${q://2_QID9/
  ChoiceTextEntryValue/3}",

 "${q://3_QID2/
   ChoiceTextEntryValue/1}",
   "${q://3_QID2/
   ChoiceTextEntryValue/2}",
 "${q://3_QID2/
   ChoiceTextEntryValue/3}",
"${q://3_QID9/
  ChoiceTextEntryValue/1}", "
  ${q://3_QID9/
  ChoiceTextEntryValue/2}",
"${q://3_QID9/
  ChoiceTextEntryValue/3}",

 "${q://4_QID2/
   ChoiceTextEntryValue/1}",
   "${q://4_QID2/
   ChoiceTextEntryValue/2}",
 "${q://4_QID2/
   ChoiceTextEntryValue/3}",
"${q://4_QID9/
  ChoiceTextEntryValue/1}", "
  ${q://4_QID9/
  ChoiceTextEntryValue/2}",
"${q://4_QID9/
  ChoiceTextEntryValue/3}",

 "${q://5_QID2/
   ChoiceTextEntryValue/1}",
   "${q://5_QID2/
```

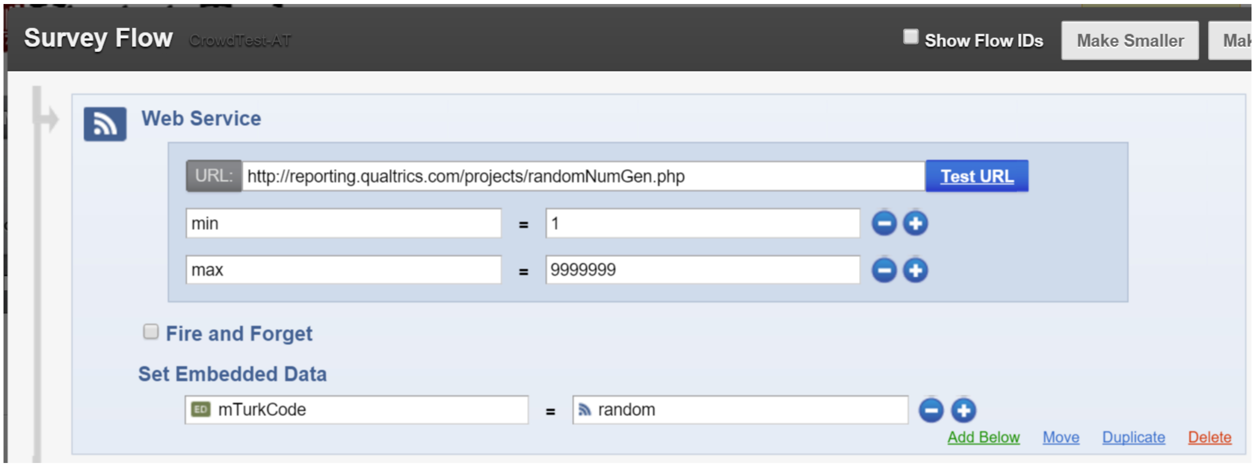
```
                                          ChoiceTextEntryValue/2}",
                                       "${q://5_QID2/
                                          ChoiceTextEntryValue/3}",
                                      "${q://5_QID9/
                                         ChoiceTextEntryValue/1}", "
                                         ${q://5_QID9/
                                         ChoiceTextEntryValue/2}",
                                      "${q://5_QID9/
                                         ChoiceTextEntryValue/3}",
        ];

        //printArray(allDes);
        cleanArray(allDes);
        getEnoughDesc(allDes);
        //console.log("PostClean");
        printArray(allDes);

        //Randomly selects 6 descriptors.
        var desc = [], f = 0, r = 0;
        for(f = 0; f < 6; f++)
        {
                r = getRandom(0, allDes.length - 1);
                desc.push(allDes[r]);
                allDes.splice(r, 1);
        }

        console.log("Final Descriptors");
        printArray(desc);
        saveEmbeddedDesc(desc);


});
```



URL: http://reporting.qualtrics.com/projects/randomNumGen.php

min = 1

max = 9999999

mTurkCode = random

Figure C.6: Random number generator. I added a web service that made a random number for each participant.

Appendix D

Media Crowdsourcing Study Data

D.1 Media Study Data

This dataset includes the crowdsourced and live participant responses, and some of the word switches made to manually perform the correct lemmatization. Please see the link below:

Media Study Zip File

D.2 Expertise Usage Study

This dataset is a subset of the prior dataset, and the data, taggings and organization are all found here:

Expertise Usage XLSX File

Appendix E

Ambiguity System Study Data

E.1 System Code

Below is a zip file to all AngularJS code to run the site:

Web Site Zip File

E.2 Raw Navigation Paths

This section documents the logs of every action for each participant in the study, separated by participant number.

Logs Zip File